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EDITORIAL NOTES.

THE Council of the Geological Society has this year made the following awards: Wollaston Medal, Arthur Smith Woodward, LL.D., F.R.S.; Murchison Medal, Walcot Gibson, D.Sc., F.R.S.E.; Lyell Medal, William Wickham King; Murchison Fund, Leonard Frank Spath, D.Sc.; Wollaston Fund, Cecil Edgar Tilley, Ph.D., B.Sc.; Lyell Fund, J. W. Tutcher and Hugh Hamshaw Thomas, M.A.

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THE proceeds of the Prestwich and Barlow-Jameson Funds have been allocated by the Council to meet part of the expenditure on the Society's publications. The Daniel-Pidgeon Fund for 1923 has been awarded to Mr. Howel Williams, of Liverpool University, for researches on the Stratigraphy and Vulcanicity of Snowdon, and a grant of £25 has been made from the Gloyne Fund for work on the bone-caves of Gower, under the superintendence of Professor W. J. Sollas.

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AT the Anniversary Meeting of the Geological Society, held on 15th February, the following new Officers and Members of Council were elected: President, Dr. J. W. Evans, F.R.S. Vice-Presidents, Dr. C. W. Andrews, F.R.S., Dr. J. S. Flett, F.R.S., and Professor A. C. Seward, F.R.S. The Secretaries and other Officers remain unchanged. New Members of Council are Professor A. H. Cox, Mr. Henry Dewey, Professor H. L. Hawkins, and Sir T. H. Holland, K.C.S.I., F.R.S., Mr. T. C. Nicholas, and Dr. L. J. Spencer.

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THE Société des Sciences, de l'Agriculture et des Arts, of Lille, has awarded Gosselet Medals, silver-gilt, large size, to Mr. W. B. R. King, Assistant to the Woodwardian Professor, Cambridge, and to Professor L. D. Stamp, of University College, Rangoon, for "work carried out in the region of the Nord during the late war".

ORIGINAL ARTICLES.

Eocene Cycles of Sedimentation.

By Professor L. Dudley Stamp, B.A., D.Sc., A.K.C., F.G.S.

IT must inevitably happen sometimes that an author does not quite convey to his readers the whole of his own conception of a subject. It may be perhaps that certain objects in his mental picture are to him so obvious as to be unworthy of emphasis, and he is apt to forget that to his readers no part of the picture is, in the first instance, obvious. From the recent paper by Messrs. A. K. Wells and S. W. Wooldridge ("The Mechanism of Sedimentation Cycles", Geol. Mag., Vol. LX, December, 1923, pp. 545–50), it is evident that I have failed to convey, to them at least, the whole of my conception of the Anglo-Franco-Belgian Basin. I apologize, therefore, to readers of my *Introduction to Stratigraphy* for any lack of clarity, and I should like to thank Mr. Wells and Mr. Wooldridge for bringing the matter into the light of day and allowing me an opportunity of stating very simply my ideas, all of them already published, on the geography of the Anglo-Franco-Belgian Basin in Eocene times. Perhaps had my critics, before rushing into print, read pages 278–9 of my book as well as page 267, the occasion would never have occurred.

It is a matter of considerable gratification to me to find that the concept of the Sedimentation Cycle, together with the inseparable idea of facies faunas, has been extensively applied by various English geologists in the past two or three years. As Messrs. Wells and Wooldridge have stated (op. cit., p. 545), I have, on more than one occasion, traced the consequences of a sea "transgressing over a steadily sinking land, outlining the sequence of events and the nature of the deposits at various stages". I have applied the principle to many widely different formations, e.g. Valentian,[1] Devonian,[2] Carboniferous,[3] Trias,[4] Cretaceous,[5] and the Tertiary of Burma.[6] When it comes to considering the Eocene strata of south-eastern England I, not unnaturally, presumed the reader to be thoroughly familiar with the consequences of marine transgression, and took this for granted in dealing with the history of the Eocene period. The great interest which attaches to the Anglo-Franco-Belgian Basin is the part which was played by movements of uplift of the Wealden dome at the critical periods between the cycles. This is merely an adjunct to, but certainly not (as my

[1] *An Introduction to Stratigraphy*, p. 87, fig. 16.
[2] Ibid., p. 116 and fig. 31, *Proc. Geol. Assoc.*, vol. xxxiii, 1922, p. 4 (Belgium).
[3] Ibid., pp. 130–3.
[4] Ibid., pp. 190–2.
[5] Ibid., pp. 240, 243, 251.
[6] Geol. Mag., Vol. LIX, 1922, pp. 481–501.

critics suggest) a substitute for, the wider movements of subsidence which took place during the Eocene period in this area. In Messrs. Wells' and Wooldridge's paper occurs the amazing statement that "we are asked to believe that an uplift of the Weald had the surprising result of inundating the uplifted area, but this is quite impossible". This statement occurs, notwithstanding the fact that I have given a series of diagrammatic sections in my book (fig. 66) especially to show the effect of the uplift of the Chalk surface of the Wealden dome relative to the remainder of the sub-Eocene Chalk surface and *at the same time combined with regional subsidence during the deposition of the London Clay.* It is definitely stated by me (p. 279) that "the sea continued to spread in all directions" and "*continued depression* has allowed the deposition of a thick mass of marine clay in comparatively tranquil deep-water conditions". Further, this regional subsidence, quite apart from any movement in the folding of the Weald, had been emphasized by me in my paper "On the Beds at the Base of the Ypresian in the Anglo-Franco-Belgian Basin",[1] where I state: "The disturbed conditions of the first inrush of the sea in Blackheath times settled down into a gentle and continuous submergence and the resumption of normal sedimentation."[2] This statement occurs in the most significant part of the paper—namely, in the Summary of Results. In the same place is the statement that "earth-movements, connected with the uprise of the Weald, caused the estuarine areas of the Upper Landenian to *sink* . . . the sea . . . flowed rapidly over these lagoon flats . . . the deposits formed during this marine invasion . . . Blackheath Beds".[3] Surely, it is clear that I have invoked the folding movements of the Wealden dome to explain only such special features as the Blackheath Pebble-Beds and the *initial* marine movements of the cycles, and *not* to explain the whole of the Eocene deposits. The sudden changes between the cycles of sedimentation, I do believe, were caused by movements in the Wealden area, and the "history of the Eocene may be summarized as a repetition of such movements",[4] at least so far as its unusual features are concerned, but nothing is said as to the Wealden movements being responsible for the extensive marine transgressions following the first changes.

My critics accuse me of inconsistency in referring to the Anglo-Franco-Belgian or Anglo-Gallic Basin as a "partially enclosed sea" and then introducing a comparison "with an enclosed sea such as the Caspian or even the Baltic Sea". As explained in the text, the Anglo-Gallic Basin must have been at times connected with the

[1] *Proc. Geol. Assoc.*, vol. xxxii, 1921, pp. 57–108. For some extraordinary reason this paper, which contains most of the detailed work on which the broader conclusions were based, is not even mentioned by my critics.

[2] p. 100.

[3] p. 99.

[4] *Introduction to Stratigraphy*, p. 267.

Southern Ocean, at other times was possibly a land-locked sea. Perhaps " possibly periodically enclosed " would have been better than " partly enclosed ", but the latter is a more generalized description.[1] When entirely land-locked, comparison with the Caspian is not, I think, unmerited ; when open, the Baltic forms a more or less parallel case. Surely, my critics are not so ignorant of the recent geological history of the Baltic as not to realize what slight—almost imperceptible—changes would convert it into a completely enclosed sea [2]—hence the word " even " in the quotation above.

I trust I have quoted sufficiently from my previous writings to show how completely Messrs. Wells and Wooldridge have misunderstood my conception of the Anglo-Gallic Basin. I will now endeavour to present, in a concise manner, my theories to explain the Cycles of Sedimentation in the Eocene, at least so far as the London area is concerned. We may note here that my critics and I are agreed on the existence of the cycles—a matter of great importance.

I find I can summarize my views of the history of the Eocene period in the very words used by my critics, " a series of uplifts alternating with periods of slow collapse." I think, however, that the slow collapse or submergence, on cessation, allowed the basins to be silted up, and that the uplifts were more of the nature of a buckling of the sea-floor, of which the Wealden dome is one " bulge ".

1. In early Eocene times a sea—the Anglo-Franco-Belgian Basin—covered the south-east of England, much of Belgium, and the north-east of France. We do not know anything of the limitations of this sea to the north-east and so cannot say whether it was ever land-locked or not. To the south-west or west, connexion was established periodically, and then only indirectly, with the Tethys or Southern Ocean.

2. Dealing only with England, one of the dominating factors was the " Eocene Amazon " flowing from the west or west-south-west and depositing its sediment in the London and Hampshire regions.

3. In the position now occupied by the Weald there existed in the sea-floor an incipient fold, possibly giving rise to a submerged shoal or even an island.

4. The Lower Landenian sea at first occupied but a minor area, but under the influence, probably, of regional depression, gradually transgressed. Its greatest extent was during the zone of *Cyprina*

[1] Since the north-eastern limit is unknown.

[2] Without reference to charts, I believe an elevation of less than 50 feet across the Sound and Belts would be sufficient. I considered it superfluous to remark that disturbances such as would produce a great anticlinal flexure in the sea-floor could scarcely be expected to arise without causing minor adjustments in surrounding regions, of which an elevation of 50 feet in one part is not an extravagant demand. In writing " enclosed sea ", I did not mean necessarily only seas which are absolutely cut off. In this case there are no such things as enclosed seas—they are all lakes.

scutellaria (Woolwich Bottom Bed in England). During this regional subsidence, however, the Wealden buckle experienced a slight folding movement, resulting in the uplift of its central portion. In the London area, as one approaches the region of movement, there is a physical break (ravinement below the basal pebble-bed of the Woolwich Bottom Bed) in the midst of the marine Landenian.

5. As a result of the cessation of subsidence the Lower Landenian sea became silted up by sediments grouped together as Upper or continental Landenian (Woolwich and Reading Beds) so that most of the eastern half was occupied by a brackish lagoon, with a truly marine phase in the extreme east.

6. The next movement of regional subsidence was heralded by a movement of uplift along the Wealden dome. Now it is almost impossible to have an anticlinal ridge formed thus without a synclinal trough on either side. A synclinal trough was actually formed in the Woolwich estuarine lagoon north of the Weald, and into the trough rushed the sea (Blackheath Sea, basal Ypresian). Waters, both marine and fresh, carried down pebbles from the uplifted area—where they had already been partly rolled—into the turbulent Blackheath sea.

7. The local movement responsible for the curious Blackheath deposits soon gave place to a slow, gentle subsidence during which the London Clay sea transgressed widely. Like the depression of Landenian times this movement ceased, and was either followed by a general silting up of the sea, or possibly by an actual general uplift.

8. The silting up of the London Clay, or the slight regional uplift, resulted in the deposition of the Bagshot Beds (continental Ypresian). I am not quite sure from his recent writings [1] whether or not Mr. Wooldridge still agrees with me that the Bagshot Beds of most of the London area are fluviatile in origin. I am inclined to regard, as he does, I believe, the Bagshot Pebble Beds of Essex as a shingle bar separating these beds from the sea,[2] for the Bagshot Beds of Essex east of the Pebble Beds appear to be of marine origin, as are also the corresponding beds in Belgium.

9. They are so poorly shown in the London area that I will not here consider the post-Ypresian cycles.

It remains for me now to examine the alternate hypothesis, admittedly incomplete, advanced by my critics. The whole point is, of course, that they have missed my idea of the Wealden folding and a regional depression in early Ypresian times being almost synchronous—the first possibly heralding the second in this particular case. I have taken it for granted that the folding of the Weald was of the nature of an ordinary "buckle" in the

[1] *Proc. Geol. Assoc.*, vol. xxxiv, 1923, p. 318.
[2] Ibid., vol. xxxiii, 1922, p. 322.

floor of a basin. My critics, in discussing my hypotheses, do not. They seem to imagine a type of folding which is extremely rare in Nature, i.e. the formation of an anticline by an upward bulge in the earth's crust, without the slightest sign of a syncline on either side. This is evidenced by their statement: "We submit that elevation of part of the sea-floor of this very shallow sea could only have one result—a further shallowing of an area which was already not much more than submerged." I submit, on the contrary, that the growth of the Wealden anticline, a normal type of fold, must almost without saying have been contemporaneous with the growth of the London syncline to the north, and it was exactly into a trough so formed that the Blackheath sea flowed over the Woolwich estuarine deposits.[1]

I must refrain from repeating here the arguments for the intermittent uplift of the centre of the Wealden dome from late Cretaceous to Middle Eocene times. I have set out the principal ones elsewhere.[2] A single one of the eight arguments there given, viz. the rapid thinning of the London Clay in a southerly direction towards the Weald, must prove that slow regional subsidence alone—as advocated by my critics—without an attendant relative uplift of the Weald scarcely meets the case.

In conclusion I will quote from my critics' closing remarks: "As regards the Wealden anticline, it would be foolish to deny that the early stages of its growth influenced Eocene sedimentation . . . as far as the London Basin is concerned, it seems more in accord with the facts to envisage a series of uplifts alternating with periods of slow collapse . . ."

There is no need to "envisage" this "new" conclusion, readers will find it most carefully illustrated in fig. 66 of my *Introduction to Stratigraphy*, or equally well in fig. 13 of the *Proceedings of the Geologists' Association*, 1921.

The Desert Shores of the Chalk Seas.

By E. B. Bailey, M.C., B.A.

(PLATES V AND VI.)

1. *The comparatively shallow Chalk Seas of the Northern Hemisphere owed much of their clarity to their situation in a geographical belt where matured desert figured as the typical associated continental form.*

It may be recalled that chalk of Upper Cretaceous age extends in Europe from Britain by way of Denmark and parts of Germany

[1] These conditions are set out in detail in my Ypresian paper (*Proc. Geol. Assoc.*, vol. xxxii, 1921, p. 71) where I definitely associate the *sinking* of the London area with the uprise of the Weald.

[2] *Proc. Geol. Assoc.*, vol. xxxii, 1921, pp. 71–3. I have purposely refrained from mentioning here, or elsewhere, anything of the ridge (now marked by the Chiltern Hills, etc.) which bounds the Anglo-Gallic Basin on the north and whose rise was probably intermittent and gradual like that of the Weald.

into Southern Russia. In England its maximum thickness is about 1,500 feet, and in southern Russia about 2,000 feet.

In considering the above proposition, evidence will be led bearing upon the following points :—

(*a*) The Franco-British Chalk Sea was bordered by a matured desert.
(*b*) This desert was a hot one, corresponding in type with the Sahara of to-day.
(*c*) The sea itself was of very moderate depth.
(*d*) Lack of rain on the neighbouring land supplied one good reason for the sea's abnormal purity.

Before going into detail, a second proposition may be stated, which it is not intended to treat as anything more than a corollary of the first.

2. *The influence of desert conditions may be traced in the widespread Cretaceous greensands of the Chalk Belt.*

J. Murray and A. F. Renard, in discussing the distribution of modern Green Sands and Muds, have remarked that " along coasts where Green Muds are laid down pelagic conditions appear to approach much nearer to the shores than where the Blue Muds prevail ", and again, that " along high and bold coasts where no rivers enter the sea, and where accumulation is apparently less rapid, glauconite appears in its most typical form and greatest abundance " (1891, p. 382). It is difficult to suppose that the Cretaceous was a time of particularly high and bold coasts, considering, for instance, the extent of the Cenomanian Transgression ; but the prevalence of Greensand may well be taken as an indication of abnormally small rivers—especially when it is remembered that the Cretaceous greensands appear to be comparatively shallow-water representatives of their class. If, then, we are right in attributing to climate an important share in cutting off river-contamination in the case of the Chalk Seas, we may almost certainly claim its aid in accounting for the widespread greensands of both Lower and Upper Cretaceous age. There is, of course, independent evidence for continuity of climatic belts during Cretaceous time. Emil Haug, in his résumé of the work of F. Roemer, M. Neumayr, H. Douvillé, and others, points to the general persistence throughout this period in southern Europe of the northern margin of an equatorial belt characterized, in its shallow-water associations, by large foraminifera, compound corals, *Rudistes*, and thick-walled gasteropods (1908–11, pp. 1169, 1366). The chemico-biological characteristic of these associations is the profligate use of carbonate of lime ; this feature reappears in the coral seas of to-day, and has been explained by the relative ease with which carbonate of lime is precipitated from warm as compared with cold water. The only thoroughly important migrations of the *Rudistes* associations are revealed in their almost complete failure in the Hauterivian and Albian stages, for which accordingly cold intervals have been postulated by Haug or his predecessors.

Evidence of the Deserts.

The Scottish evidence which points to the existence of desert shores bordering the Chalk Seas will be taken first, since it supplied the key to the whole. It should be understood that the field-work which I, in co-operation with my colleagues, G.W. Lee, J. B. Simpson, and W. Manson, have done in this connexion has been carried out in the course of the recent geological survey of Mull and Morvern; and I must thank the Director of the Survey for permission to publish the results gathered together in the present paper. Two official memoirs are in the press dealing respectively with the Tertiary and the Mesozoic geology of the district, and readers are referred to them for necessary amplification of local detail.

Once field-work in Scotland had suggested the idea of the desert shores, it was natural to search the literature of other countries for support or contradiction, as the case might be. It will probably be admitted, by those who look at the digest which follows of W. F. Hume's researches in Ireland, and those of L. Cayeux' in France, that the general accord is more than anyone could have ventured to expect.

Before proceeding to a consideration of the facts, new and old, it may be advantageous to explain the mental equipment with which the subject was attacked. Two phenomena presented themselves for explanation at the very threshold of the inquiry: (1) small perfectly rounded grains of quartz; and (2) exceptionally pronounced silicification. Let us consider how these phenomena have been interpreted in other connexions.

Millet-seed Sands.—Scottish geologists live so constantly among igneous rocks that they have acquired the habit of examining with a lens everything they meet. It is not surprising, therefore, that, under the lead of J. G. Goodchild (1899, pl. xi) they have given great attention to the rounding of quartz grains, in sands and sandstones, as an indication of desert conditions of transport. Goodchild derived his inspiration directly, or indirectly, from J. A. Phillips, who seems to have been the first to point the moral of millet-seed sands (1881, p. 13). Phillips, in this matter, had the great advantage of being in touch with the researches of A. Daubrée and H. C. Sorby. The former's experiments lead to the conclusion that subaqeous rounding of quartz grains only becomes utterly impossible at about 0·1 mm. grain-diameter, and is appreciable, though at best very slow, at 0·5 mm. (1879, pp. 250–8). He did not discuss wind-rounding. Sorby pointed to the perfect rounding of Egyptian desert sand (1880, p. 61), but did not, at the time, claim wind-rounding for any of the rounded grains he knew so well in certain British sandstones.

One must admit, in the light of Daubrée's work, that no complete separation can be established between wind- and water-rounding as regards the size of the grains affected—A. R. Hunt, indeed

(1887, p. 505), has stated that water-rounding can be noticed in the case of quartz grains drifting to and fro on a sandbank in the English Channel, even when their diameters fall as low as 0·3 mm.; but probably all observers agree that wind is in general much more effective in rounding grains than water. One knows quite well that it is possible to enjoy a bathe on a sandy shore with half a gale blowing, while it would be agony to sit at such a time unclad among the neighbouring sand dunes. I am inclined to say from my observational experience of gravels, conglomerates, sands, and sandstones that water dealing with quartz (or quartzite) will only commonly produce perfect ellipsoidal rounding of boulders, pebbles, and grains when their mean diameters lie between 1 m. and 1 mm., and that wind will perform the same task for grains measuring from 3·0–0·2 mm. According to this estimate, perfectly rounded grains under half a millimetre in diameter, so small, that is, as to require a pocket-lens[1] for their ready appreciation, strongly suggest wind-transport at some stage in their career. I agree with Phillips and Sorby that the sand grains of our British coastal dunes are not distinguishable from those of the neighbouring sea-shores, though stationary rock surfaces, over which these grains have hurried, are in many cases conspicuously rounded by the sand-blast. On the other hand, G. B. Cressey finds wind-rounded grains commonly developed in the sand dunes of Lake Michigan in Indiana in strong contrast to the subangular grains of the lake shore (1922, p. 251). It would seem therefore that a pronounced development of rounded grains betokens wind-action with more scope than our limited coastal dunes afford, but not necessarily of Saharan magnitude.

Apart from the question of possible water-rounding, there are two main difficulties which must be faced in dealing with rounded grains in geology: (1) such grains may have travelled far from the scene of their rounding; and (2) they may have been rounded near at hand, but in past geological ages. Every case must be decided on its own merits.

Excessive Silicification.—Let us now turn from the question of rounding to that of silicification. G. W. Lamplugh's observations on surface-silcretes in South Africa, must have brought home to many British readers the rapidity with which silicification sets in among the sands of that region (1907, p. 198). This silicification is not all of one sort. H. H. Thomas described Lamplugh's specimens as consisting of millet-seed sands bound by a chalcedonic matrix (1907, p. 211). On the other hand A. W. Rogers found that the original quartz grains are at places converted into bipyramidal crystals (1905, p. 359). It is obvious, in this latter case, that true

[1] It is important to realize that measurements of the type quoted only require a pocket-lens and a half-millimetre scale, and so are quite within the reach of any field-geologist; and also that the description perfectly rounded should only be applied to sand grains which have a smoothed surface with the pearly lustre of frosted glass.

surface quartzite has resulted, and that the process is comparable with what has been described in old rocks by T. G. Bonney (1879, p. 666), H. C. Sorby (1880, p. 61), and J. A. Phillips (1881, p. 13). S. Passarge, with his wide acquaintance of the Kalahari desert, interprets the exceptionally pronounced silicification met with in South Africa as a desert phenomenon. According to him, silicification is a pronounced phenomenon in hot countries if the rainfall escapes by evaporation instead of by drainage (1904, pp. 616–18).

With this introduction, the facts collected in the various countries will need very little additional comment.

Scotland.

In 1878, J. W. Judd presented a detailed account of a very interesting discovery which he had already announced in 1872. He had found a peculiar condensed representative of the Upper Cretaceous System in Mull and Morvern (1878, pp. 662, 666, 681, 683, 728–40). Upper Cretaceous rocks had not previously been known *in situ* anywhere in Scotland. The series begins with Cenomanian Greensand resting transgressively on various stages of the Jurassic; and Judd pointed out that its behaviour afforded yet another example of the widespread Cenomanian Transgression so ably emphasized by E. Suess two years before in his *Enstehung der Alpen*.

A couple of representative sections are given below measured in feet :—

	Beinn Iadain. Morvern.	*Gribun.* Western Mull.
Upper Senonian Chalk (silicified), with *Belemnitella mucronata* .	3	10
White Sandstone . . .	35	10
Cenomanian Greensand, with banks of *Exogyra conica* . . .	40	20
	78	40

The two sections lie 20 miles apart. The Beinn Iadain measurements are taken from Judd's own account. In the summer of 1922, they were confirmed for the Geological Survey by J. Simpson and W. Manson, whose figures agree sufficiently closely with those quoted. In both localities, a very interesting feature, fully realized by Judd, is the silicification of the chalk. The altered rock has retained its chalky appearance, but it does not effervesce with acid, for its carbonate of lime is replaced by crypto-crystalline silica. The replacement has been so conducted that T. Rupert Jones, who supplied Judd with microscopical notes, was able to determine foraminifera, *Inoceramus*-prisms, and sponge-spicules.

There is scarcely any evidence for the existence of desert shores during the accumulation of the Cenomanian Greensand. The parts I know best consist of very fine-grained sandstone (with scattered glauconite) merging into limestone. The sand-grains are generally too small to be readily rounded either by wind or water; but one specimen, collected by Simpson and Manson from an *Exogyra* bank

in the Beinn Iadain exposure, shows a very few, relatively large grains, 0·2 mm. in diameter; and these are beautifully rounded.

The White Sandstone is always distinctly coarser than the Greensand, though still fine-grained. In Beinn Iadain, Simpson and Manson found rounded grains characteristic of the whole deposit, and their specimens include the best examples of fine-grained millet-seed sandstone I have ever seen (Pl. V, Fig. 2). The rock consists in large measure of perfectly rounded ellipsoidal grains, often measuring about 0·4 mm. across, and sometimes no more than 0·2 mm.

In the Loch Aline section, on the Morvern side of the Sound of Mull, the White Sandstone is rather finer in texture, and though it contains perfectly rounded grains, 0·2–0·3 mm. in diameter, these are relatively much less abundant than at Beinn Iadain, 7 miles away.

At Gribun, the White Sandstone is thoroughly fine, with 0·2 mm. as a very common measurement for its grains. Even so, a few of these small grains are beautifully rounded; though, mingled among their subangular companions, they are rather apt to escape attention.

I consider that the rounded grains of the White Sandstone are unquestionably wind-worn. The sandstone containing them shows traces of marine shells in its upper and lower parts as exposed in Beinn Iadain, and I think that it probably represents a desert sand blown into the sea. Against this interpretation, there is always the possibility that the sands may have been derived from some desert-sandstone of pre-Cretaceous age. Careful exploration lends no support to such a suggestion. The Cenomanian Greensand in Mull and Morvern is separated from gneiss by a sequence commencing with Trias and locally extending upwards to Inferior Oolite. I have carefully examined the complete sequence in Ardnamurchan, a little farther north, without finding rounded grains. The Trias is the formation in which one might most naturally expect to find such grains, since the New Red Sandstone (? Trias) of Central Scotland is often of millet-seed type. The Ardnamurchan Trias is thin, but its Gribun representative is fully 200 ft. thick, and again contains nothing but subangular and blunted grains.

I have no direct observation to offer regarding the conditions under which the Upper Senonian Chalk accumulated; but its later history, involving among other things its silicification, seems to bespeak its exposure to desert conditions after its upheaval to form dry land. The Morvern sections have yet to be studied in this connexion, but those of Gribun and Carsaig, 10 miles distant from one another in Mull, tell a very consistent story.

At Gribun, the most convenient exposure of the Upper Cretaceous rocks is afforded by a miniature roadside cliff near the ruins of Clachandhu. Silicified chalk is here seen *in situ* resting upon 10 ft. of the White Sandstone, with the top of the Cenomanian Greensand cropping out below. The silicified Chalk is traversed in every direction by veins of sand bound together into a silcrete (to borrow Lamplugh's term). The matrix holding the grains is crypto-

crystalline silica, like that replacing the chalk, but breaking with a more flinty fracture. The grains themselves are of quartz, and include a notable proportion of beautifully rounded individuals, many about 0·4 mm. in diameter, and some no more than 0·2 mm. The following deductions are necessary :—

(1) The chalk was still a limestone when upheaved, since it weathered in carious fashion.

(2) Its crevices were filled in by drifting sand, including many wind-rounded grains.

(3) The complex of chalk and sand was silicified in a fashion highly characteristic of desert regions.

There is no source *in the Gribun district* from which the rounded grains of the sand-veins could have been derived. There are, it is true, rounded grains in the White Sandstone below the silicified Chalk, but these are relatively few, small, and inconspicuous. This statement loses much of its weight—considering that a millet-seed facies of the White Sandstone has been demonstrated in Morvern; but there still remains the coincidence of finding millet-seed sand-grains, and excessive silicification, combined in one and the same rock. Accordingly, I feel justified in claiming that the Gribun Chalk was subjected to a desert climate after its upheaval.

The Tertiary sandstone, of supposed desert origin, overlying the Chalk of the Gribun district, is only a very few feet thick (Pl. VI, Fig. 1). It is noteworthy, however, because it shows a definite tendency to silicification by addition of crystal facets to its grains, where, as is generally the case, these latter are not enclosed in crypto-crystalline silica. The phenomenon of crystal growth is particularly marked in a waterfall-exposure afforded by a stream which empties into the sea close to Caisteal Sloc nam Ban. There can be no doubt that the sandstone in this stream is Tertiary, since its bottom part serves as a matrix to Chalk debris, now silicified. Many of the quartz grains exhibit a rounded form partially masked by new facets.

At Carsaig, silicified chalk is found as numerous fragments embedded in a sandstone with a large proportion of rounded grains, 0·2–0·3 mm. in diameter. The chalk fragments are enveloped in a halo of crypto-crystalline silica enclosing adjacent grains of the sandstone (Pl. VI, Fig. 2, shows a slice cut from such a halo). The evidence that these fragments were embedded as limestone, and subsequently silicified, is decisive.

It is very natural to regard the desert, which according to hypothesis embraced the Mull district at the initiation of the Tertiary era, as nothing else than an extended continuation of that which at an earlier date bordered the Upper Cretaceous sea of the same locality.[1] Although Scottish evidence is silent on this point, such a

[1] In the course of this paper it is tacitly assumed that Cretaceous times gave place to Tertiary on the elevation of the Upper Senonian Chalk of Mull into dry land. Possibly some day the change of climate from dry to moist will be found a more useful criterion for separating the two systems.

theory of desert-continuity supplies at once a partial explanation for the clarity of the shallow Chalk Sea of Britain and France ; and, as will be shown in the sequel, Cayeux' observations in the latter country prove that the Chalk from top to bottom contains small beautifully rounded grains of quartz—though, of course, there are exceedingly few of them in the purest varieties.

Passing on in time, we find that most of the early Tertiary history of Mull is a record of terrestrial outpourings of basalt lava. In the south-west part of the island, the lava-flows are interstratified with occasional lignites ; and, at Ardtun, 7 miles distant from Gribun, they enclose the famous leaf-beds first described by the Duke of Argyll. These latter are formed of close-packed layers of leaves, shed autumn after autumn by deciduous trees, and collected on the bottom of a still expanse of water. J. S. Gardner has claimed that the Ardtun flora is older than the Thanet flora of Gelinden (1887, pp. 292, 299). At any rate, A. C. Seward and R. E. Holttum state in the Tertiary Mull Memoir (now in the press) that the Ardtun leaf-beds betoken a fairly moist warm-temperate climate firmly established in Mull at some stage of the Eocene. Moreover, the Mull lignites and leaf-beds are not the earliest indication of moist conditions in the district ; almost everywhere, the lava pile of Mull and Morvern rests upon a few feet of mudstone, which, as G. W. Lee has suggested (1911, p. 39), is probably a weathered ash. Not only so, but in south-eastern Mull, this mudstone often overlies, or else serves as matrix to, a flint-conglomerate with abundant water-rounded pebbles. It would seem, then, that the initial desert of the Tertiary landscape was soon dispossessed by river, pool, and woodland. It is, therefore, satisfactory to find almost conclusive evidence that the silicification of the Chalk was carried out before the moist conditions had set in. This evidence comes from south-eastern Mull, and is briefly as follows.

About a third of a mile west-north-west of Torosay Castle, there is a small exposure of grey limestone (almost certainly Senonian) which shows very partial patchy silicification throughout and is overlain by a layer consisting mainly of white flint. The material of this top band is precisely similar to that of the water-rounded pebbles of the overlying basal Tertiary conglomerate already mentioned. Silicification at Torosay had therefore taken place before this conglomerate was fashioned ; and it seems reasonable to transfer this conclusion to the Gribun exposures, where one can only see for certain that it had not set in before the upheaval of the Chalk.

History.—The following are a few dates in connexion with the inquiry :—

In 1878, Judd interpreted the White Sandstone of Morvern as estuarine. It is not surprising that he overlooked the millet-seed grains, since Phillips' paper did not appear till three years later. Judd interpreted an old statement of Macculloch's as showing that the sandstone contains a thin seam of lignite. There appears little justification for this inference because : (1) lignite certainly occurs in sandstone above the Chalk ; (2) no one suspected the existence of the chalk until Judd examined the sections ; (3) landslips

are common; (4) Judd, Simpson, and Manson have failed to find lignite under the Chalk.

In 1909, I found the Torosay limestone and flint, and the overlying flint-conglomerate.

In 1920, a few exciting minutes supplied the conclusions stated above in regard to the roadside cliff-exposure at Gribun. In the next fortnight several confirmatory sections were examined, including that at Carsaig, where Lee several years before had found that Judd's silicified Chalk, where accessible, occurs as fragments enclosed in a Tertiary sandstone.

In 1921, the results of the previous year's work were published (1921, p. 36), and a most helpful letter was received from W. B. Wright. He pointed out that: (1) the Mull desert might some day be fitted into place in a Saharan belt extending round the world; (2) the change from a Saharan climate to a Warm Temperate climate does not involve a particularly great climatic revolution, since Saharan and Warm Temperate belts are natural neighbours in climatology; and (3) that possibly the apparent climatic wanderings might eventually be interpreted in Wegener terms of continental and polar migration. Wright's conception of climatic belts, which I had previously overlooked, henceforward became a leading incentive to research, and is now embodied as one of the main principles of the present paper.

In 1922, I visited the Morvern equivalent of the Gribun White Sandstone as exposed on the shores of Loch Aline. Inspection showed that this sandstone must be admitted to contain wind-rounded grains—I had previously felt that the Gribun evidence was inconclusive in this respect. The Loch Aline exposures, however, are unsatisfactory in that the Chalk is missing, so that the date of the White Sandstone can only be fixed, on local evidence, as later than that of the underlying Cenomanian Greensand. Accordingly, on Lee's advice, I asked Simpson and Manson to visit Beinn Iadain, which they did with the happy results already indicated.

Ireland.

Investigation of the Cretaceous of Antrim is mainly due to R. Tate, C. Barrois, and W. F. Hume. The sequence resembles somewhat closely that of Mull and Morvern. A. J. Jukes-Browne (1912, p. 512) summarizes its features in the following table:—

Tate's Divisions.	Hume's Zones.	Feet.
5. White limestone .	Zone of *Belemnitella mucronata* . . }	100
	,, *Actinocamax quadratus* . . }	
	,, *Actinocamax verus* . .	3 to 5
4. Chloritic Chalk =	,, *Echinocorys gibbus* . .	3 to 4
3. Chloritic sands and sandstones.	*Inoceramus* zone (Upper Chalk) .	6 to 16
	Zone of *Exogyra columba* . .	4 to 15
2. Yellow Sandstones =	,, *Ostrea carinata*. . .	4 to 30
1. Glauconitic sands =	,, *Exogyra conica* . .	4 to 16

The white limestone is a hard chalk with flints; but much of it, at any rate, has escaped silicification of Scottish type, for Hume gives three analyses showing over 99 per cent $CaCO_3$. There is some difference of opinion regarding the exact placing of the various zones of this condensed series; but Jukes-Browne seems to suggest that the three lower, including *E. conica* to *E. columba*, may be given to the Cenomanian, and the five upper to the Senonian, leaving the Turonian unrepresented. The sequence varies according to locality, and in places the *B. mucronata* zone rests, with pebbly base, directly upon the pre-Cretaceous floor.

Hume has given a detailed account of the micro-mineralogical

features of the series. In every lithological zone, he notes rounded quartz grains (1897, pp. 546, 569, 571, 573, 575, 576, 579, 580). The occurrences in the white limestone come from the pebble beds at its local base ; in one such rock, he records " extremely rounded grains of transparent quartz, having an average diameter of ·5 mm." (1897, p. 546) ; in another, after sorting a residue that would pass a sieve of 2·5 meshes per mm., but not one of 5 per mm., he remarks that " colourless quartz-grains make up the greater part . . . showing the characteristic rounded outlines " (1897, p. 580)—such grains must have been less than 0·4 mm. in their largest diameter.

Hume apparently regards these rounded grains as derived from pre-Cretaceous sandstones (1897, p. 576). It would be dangerous, therefore, to overstress their significance ; but in the light of the Scottish evidence I am inclined to interpret them as the product of an Upper Cretaceous desert.

ENGLAND.

The Geological Survey Memoir on the *Cretaceous Rocks of Britain*, written by Jukes-Browne, with chapters by W. Hill, contains a wealth of information, and though it includes few statements regarding the shape of quartz grains, it has supplied most of the instances of rounded grains cited below.

Devonshire presents a lithological sequence of Upper Cretaceous rocks with distinct affinity to that of Antrim, Mull, and Morvern. A basement greensand, referred by Jukes-Browne to the Selbornian, is overlain by a condensed series of thin, sandy limestones admittedly Cenomanian. A residue with diameters 1·0–1·5 mm. obtained from a low position in these Cenomanian limestones (*Acanthoceras mantelli*), consisted, according to Hill, almost entirely of rounded quartz grains (1903, p. 274). Higher up in the sequence (*Actinocamax plenus*), completely rounded quartzes were noted in two residues, one with diameters between 0·5–1·0 mm. and the other above 1·0 mm. (1903, p. 275). Higher up again, in the Beer Stone (*Rhynchonella cuvieri*) of the Turonian, Hume is quoted by Hill as stating " The material exceeding ·5 mm. only included a few silicified snow-white organic fragments and some rounded quartz " (1903, p. 510).

In other parts of the country rounded quartz grains have been noted as follows :—

Cenomanian : *Holaster subglobosus* Zone above Totternhoe Stone, less than 0·55 mm. (Hill, 1903, p. 311).

Turonian : *Rhynchonella cuvieri* Zone, Melbourn Rock, less than 0·53 mm. (Hill, 1903, pp. 503–4) ; *Terebratulina gracilis* var. *lata* Zone, Isle of Wight, small (Hume quoted by Jukes-Browne, 1904, p. 364).

Senonian : *Micraster cortestudinarium* Zone, Swanage (Hume, 1893, p. 59). Hume's remark in this instance is that quartz occurs of every shape " from perfectly rounded to strikingly angular ".

He adds that such rounded quartzes are in a minority in the English Chalk.

The list is not imposing; but it seems to bear out L. Cayeux' more detailed examination of the Parisian basin dealt with in the following section.

Meanwhile, one may direct attention to another feature of quartzes of the English chalk which can be paralleled in France, namely, their occasional possession of crystalline facets—sometimes, according to the descriptions, showing wear. This feature occurs also in one of the Antrim sands (Hume, 1897, p. 569), and is strikingly shown in the Devonshire Cenomanian (Hill, 1903, p. 274). Other references are Hume, 1893, pp. 25, 36. The possible significance of these quartz crystals, where they show evidence of transport, will be discussed after an outline has been given of the French evidence.

France.

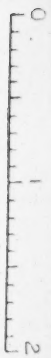
The Chalk of the Parisian basin has been studied intensively by L. Cayeux. He has divided the basin into districts, and has given individual treatment to the zones developed in each district. His many observations are recorded in detail, and in the end he remarks: "I have not observed a single chalk, however fine, which does not include grains of rounded quartz, measuring at least 0·2 mm. Diameters of 0·3 and 0·4 mm. are frequent." These relatively large individuals, though constantly represented, are not so numerous as others of angular or blunted form, often measuring well under 0·1 mm. across. Cayeux is so much impressed by the obvious correlation of shape and size, that he suggests that the smaller grains have been carried most of their journey in comparatively superficial currents of the sea, while the larger grains have been rolled along the bottom (1897, p. 546). I must confess that to me it seems impossible that quartz grains can be rounded by travel over a floor of calcareous ooze. It is preferable to suppose that the grains measuring tenths of a millimetre were already rounded under desert conditions before entering the Chalk Sea, while the grains measuring hundredths of a millimetre had escaped rounding owing to their minuteness. It is a striking feature of modern desert sand that the larger grains are very much more rounded than the smaller (Pl. V, Fig. 1).

Cayeux' results are interesting in other respects (1897, pp. 257, 417). He found quartz the fundamental constituent of the washed mineral residue of Parisian chalks. The various forms in which the quartz occurs are:—

(*a*) Rounded unpolished grains.
(*b*) Blunted angular grains—the common type.
(*c*) Limpid unworn fragments.
(*d*) Aggregates.
(*e*) Crystals, often appreciably rolled.

The aggregates seem restricted to the north part of the Parisian

1. Giza, Cairo.

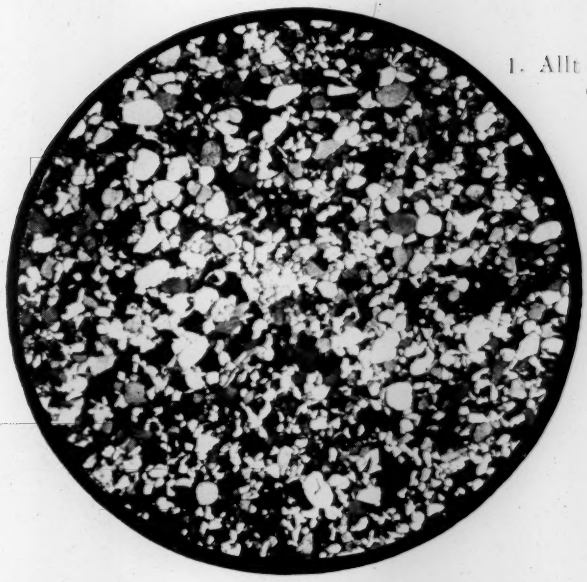


2. Beinn Iadain, Morvern.

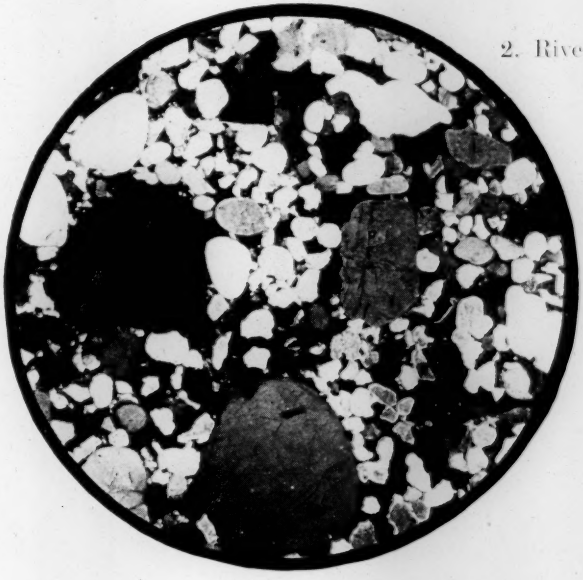
Photo J. Rhodes.

ISOLATED SAND GRAINS FROM MODERN SAHARA AND FROM UPPER CRETACEOUS WHITE SANDSTONE OF MORVERN, SCOTLAND.
Reflected Light, 23 diams.

[*To face p. 112*



1. Allt na Teangaidh, Gribun.



2. River by Roadside, Carsaig.

Photo J. Rhodes.

Basal Tertiary Sandstone from South-West Mull, Scotland. × Nicols. 14·5 diams.

basin and the district of Bray. In the north, they are sometimes relatively abundant. It is tempting to regard them as representing the break-up of surface quartzites formed in a neighbouring desert—in one case Cayeux notes that the individual grains of an aggregate are themselves rounded (1897, p. 225).

The worn crystals may well bear witness to silicification proceeding in the desert of our hypothesis. In two cases, Cayeux notes that round grains of quartz have been enlarged with an addition of crystal facets (1897, pp. 267, 320); but he attributes their change to a secondary growth after entombment in the chalk. The occurrence of quartz crystals in geodes of the chalk, though exceptional, shows that it is unsafe to claim any quartz crystal as detrital unless it shows signs of wear and tear (1897, p. 417).

America.

It is easy to realize, from inspection of textbooks, that the American Cretaceous includes a *Rudistes* development, typical chalk, æolian deposits, and rich plant-bearing strata. Whether the residues from American chalk suggest contemporaneous desert shores, is a point which can safely be left to our Transatlantic cousins to decide.

Hot or Cold?

There is little doubt that the deserts which diversified the Chalk Belt must have been hot deserts of Saharan type. It is true that occasional erratics are met with in the chalk and that their carry has been variously ascribed to floating ice or vegetation; but A. de Lapparent has remarked that with palms in Silesia and figs in Greenland, Lat. 70°, it is impossible to think of ice at our existent pole (1892, p. 1179). In conformity with this, Cayeux (1897, p. 540) has noted that the algal development of the Parisian Chalk is reminiscent of present-day plankton at the equator or in the tropics; and J. Gwyn Jeffreys (1878, pp. 85, 86) has compared the molluscs of the English Chalk with modern tropical assemblages living at less than 50 fms. below low-water mark. Moreover, the Chalk Belt is followed southwards by the *Rudistes* Belt, where an extravagant development of calcareous material bespeaks, as already noted, thoroughly warm water conditions.

Depth of Chalk Sea.

The depth of the Chalk Sea has furnished the subject of one of the classical controversies of geological science. It is unnecessary to recapitulate the history of research, since it is already placed before the reader in Cayeux' discussion (1897, chaps. xiii and xiv). His Bibliography contains 312 entries; and its completeness is typical of his work as a whole.

Cayeux regards the Chalk as having collected at moderate depths, and chooses 150 fms. as a representative figure. A few of the statistics with which he supports his conclusion are as follows:—

Molluscs (1897, p. 503).

Three-quarters of the Chalk molluscan *genera* have survived till to-day, and 30 of them were dredged by the *Challenger*. All the latter are represented between 0 and 100 fms., and only 10 reach the 500 fm. line. As regards the *species* which to-day represent these 30 surviving Chalk genera, 266 occur between 0 and 100 fms., and 132 in deeper zones (14 common to both).

Echinoderms (1897, p. 506).

In spite of the deep-sea facies of some of the Chalk echinoderms:—

(1) No surviving Chalk genus is at present restricted to depths greater than 150 fms.

(2) Most live higher.

(3) The number of species which at present live in the *Globigerina* ooze is excessively small (the least depth at which the *Challenger* dredged *Globigerina* ooze was 275 fms.—1891, Chart 27—and 2,000 fms. was found to be the typical depth for the deposit—1891, p. 215).

Sponges (1897, p. 509).

The Chalk has been compared with modern abyssal oozes on account of its containing many hexactinellid sponges. On the other hand, the proportion of hexactinellid forms in the Chalk, as compared with tetractinellid, is reminiscent of present day associations at about 150 fms.

Foraminifera (1897, p. 513).

Prestwich is quoted as saying that, of 110 species of foraminifera of present-day *Globigerina* ooze accumulated on the Atlantic bottom, 53 are known in the Crag, 28 in the London Clay, and 19 in the Chalk.

Invertebrates in General (1897, p. 517).

(1) No invertebrate Chalk *genus* lives to-day exclusively at greater depths than 150 fms.

(2) Very many do not pass this depth.

(3) The great majority of *species* representing these genera do not pass 150 fms.

(4) Among those that do, many occur both above and below.

(5) In fact, only a small number live exclusively below 150 fms.

(6) And very few are restricted to the *Globigerina* ooze.

It is obvious that further acquaintance with deep-sea faunas may modify the details of Cayeux' statement very considerably; but it is not likely to upset the balance of the evidence he has marshalled in favour of a very moderate depth for the typical area of the Chalk Sea which he has considered so thoroughly.

Purity of Chalk Sea.

If one accept Cayeux' 150 fms. as a representative figure for the depth of the Chalk Sea in the Franco-British area, one is immediately faced with a difficulty in regard to the wonderful freedom from terrigenous pollution which characterizes much of the chalk. This purity has helped to support the hypothesis of abyssal conditions of deposit. If the modern *Globigerina* ooze were deprived of its volcanic contamination, it would compare closely with white chalk in chemical composition.

Cayeux faces the difficulty, and enunciates the conclusion that *every epoch carries its own scale of bathymetric distribution for sedimentary types* (1897, p. 539). In his enumeration of the factors which control the distribution of sediment, it is exceedingly

interesting to find the following statement: "The depth and distance from land, at which pelagic and terrigenous deposits join hands, depend in some measure upon the activity of atmospheric precipitation" (1897, p. 538).

One feels that the sentence just quoted may well be construed as a prophecy of the contents of the present paper. I admit that the agreement is reassuring; but it is possible that adherents of the deep-water school may, if they choose, advance a claim that they, too, have in a measure anticipated my desert hypothesis. At any rate, Jukes-Browne has suggested that the purity of the chalk, and at the same time its persistent contamination with terrigenous material, are characters "comparable to those of recent oceanic deposits formed at a great distance from land, and in which the quartz-grains are merely quartz dust originating over some dry tract of land and blown out to sea during dust storms" (1904, p. 369). It is somewhat curious, too, that the most direct reference to desert influence upon marine sedimentation that I have been able to find in Murray and Renard's *Deep-sea Deposits* emphasizes the wide distribution of wind-carried dust. They point out that even the red-clays of the ocean abysses are appreciably contaminated with recognizable wind-borne detritus where they approach the Sahara and the desert regions of Australia; a sample which they illustrate contains many quartz grains, but none of them has a diameter more than a few hundredths of a millimetre (1891, p. 195; pl. xxvi, fig. 3).

BIBLIOGRAPHY.

1878. J. Gwyn Jeffreys, "Address Biol. Sect. Brit. Assoc. (Plymouth, 1877)": Sections, p. 79.

1878. J. W. Judd, "Secondary Rocks of Scotland: Third Paper, The Strata of Western Coasts and Islands": *Quart. Journ. Geol. Soc.*, vol. xxxiv, p. 660.

1879. T. G. Bonney, "On the Microscopic Structure of some Shropshire Rocks": *Quart. Journ. Geol. Soc.*, vol. xxxv, p. 662.

1879. A. Daubrée, *Géologie Expérimentale.*

1880. H. C. Sorby, "Presidential Address": *Quart. Journ. Geol. Soc.* vol. xxxvi, Proc., p. 46.

1881. J. A. Phillips, "On the Constitution of Grits and Sandstones": *Quart. Journ. Geol. Soc.*, vol. xxxvii, p. 6.

1887. A. R. Hunt, "The Evidence of the Skerries Shoal on the wearing of fine sands by Waves": *Trans. Devon Assoc. Advanc. Sci. Lit. and Art*, vol. xix, p. 498.

1887. J. S. Gardner, "On the Leaf-Beds and Gravels of Ardtun, Carsaig, etc., in Mull": *Quart. Journ. Geol. Soc.*, vol. xliii, p. 270.

1891. J. Murray and A. F. Renard, *Deep-sea Deposits.*

1892. A. de Lapparent, *Traité de Géologie*, 3rd ed.

1893. W. F. Hume, *Chemical and Micromineralogical Researches in the Upper Cretaceous Zones of the South of England.*

1897. L. Cayeux, "Contribution a l'étude micrographique des terrains sedimentaires. II. Craie du Bassin de Paris": *Mem. Soc. Geol. du Nord*, Tome iv, p. 207.

1897. W. F. Hume, "The Cretaceous Strata of County Antrim": *Quart. Journl Geol. Soc.*, vol. liii, p. 540.

1899. J. G. Goodchild, "Desert Conditions in Britain": *Trans. Edin. Geol. Soc.*, vol. vii, p. 203.

1903. A. J. Jukes-Browne with W. Hill, "The Cretaceous Rocks of Britain": *Mem. Geol. Surv.*, vol. ii.
1904. A. J. Jukes-Browne with W. Hill, "The Cretaceous Rocks of Britain": *Mem. Geol. Surv.*, vol. iii.
1904. S. Passarge, *Die Kalahari.*
1905. A. W. Rogers, *An Introduction to the Geology of Cape Colony.*
1907. G. W. Lamplugh, "The Geology of the Zambesi Basin around the Batoka Gorge (Rhodesia)": *Quart. Journ. Geol. Soc.*, vol. lxiii, p. 162. (Petrographical Notes by H. H. Thomas.)
1908–11. E. Haug, *Traité de Géologie*, vol. ii, pt. ii.
1911. G. W. Lee in Summary of Progress for 1910: *Mem. Geol. Surv.*, p. 39.
1912. A. J. Jukes-Browne, *The Student's Handbook of Stratigraphical Geology*, 2nd ed.
1921. E. B. Bailey in Summary of Progress for 1920: *Mem. Geol. Surv.*, p. 36.
1922. G. B. Cressey, "Notes on the Sand Dunes of North-Western Indiana": *Journ. Geol.*, vol. xxx, p. 248.

The Crystalline Metamorphic Rocks of South-Western Togoland.

By Thomas Robertson, B.Sc., A.Inst.M.M.

(PLATES VII AND VIII.)

Introduction.

SOUTH-EAST of the Togo Range, which traverses southern Togoland, in a N.N.E.–S.S.W. direction, lies a tract of low country underlain by crystalline metamorphic rocks. Out of this low-lying land rise island mountains, some of which are composed of intrusive igneous rocks. Faulted outliers of rocks of the Togo series which forms the hills of the Togo Range also occur in the low ground and in places form ridges parallel to the main Togo mountain scarp. The altered sedimentary rocks of the Togo series appear to rest unconformably on the Crystalline Metamorphic Series, but have been to a certain extent folded, and possibly locally recrystallized with them.[1]

The main road from Pode to Atakpame, running N.N.E. along the eastern side of the Togo Range, marks out roughly the boundary between the two series. Going along this road we pass alternately across the sandstones, phyllites, and quartzites of the Togo series and the gneisses and mica-schists of the more highly altered eastern rocks. Complications due to intrusions of igneous rocks along the contact appear here and there, and as these intrusions are sometimes themselves foliated, the task of placing any given crystalline rock is not easy. The direction of strike of the foliation planes is almost invariably between N.E.–S.W. and N.N.E.–S.S.W. in the rocks of the Crystalline Metamorphic Series.

As exposures are scanty and the ground was not gone over in detail, but only examined by means of a series of traverses, it is not possible to enter much into the relationships of the various

[1] For an outline of the geology of Togoland see W. Koert, *Beitr. zur geol. Erforsch. der deutsch. Schutzgeb.*, Heft 1, 1913.

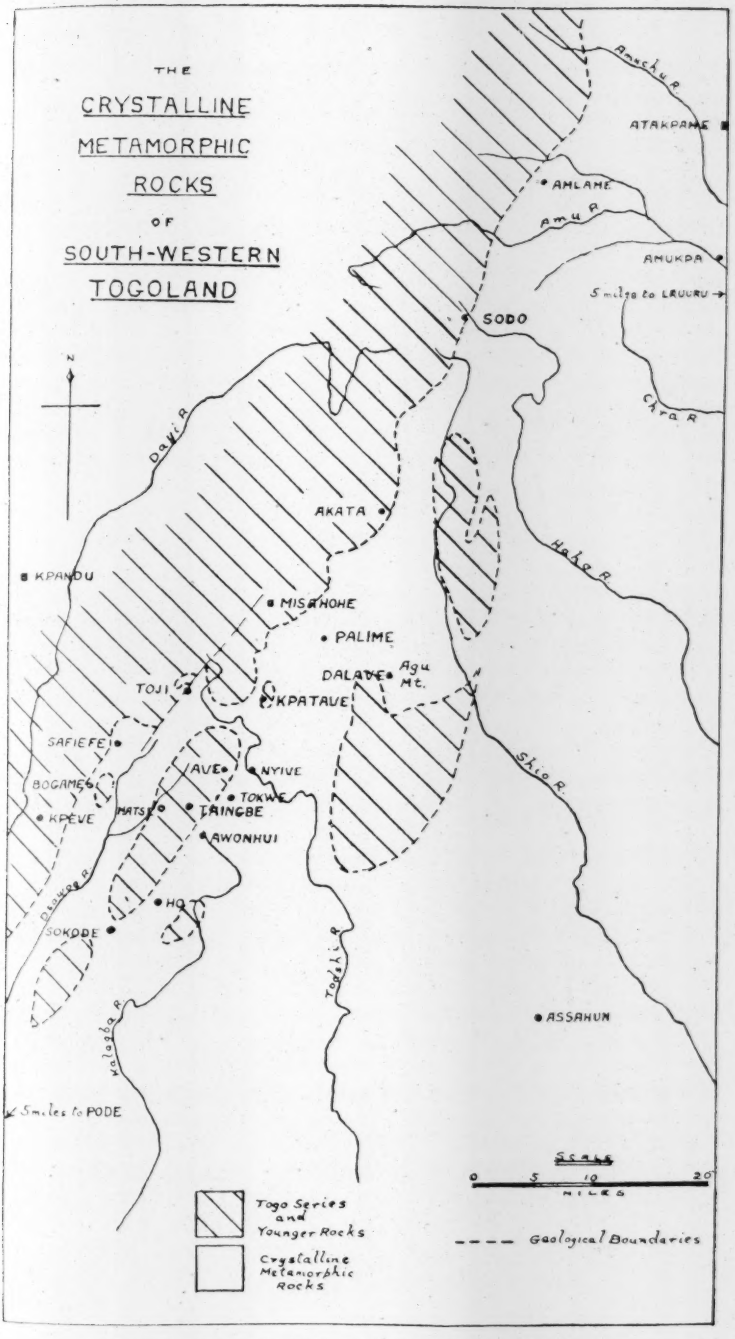


FIG. 1.—Geological Map of South-Western Togoland.

rock types to one another. Descriptions of the principal rocks met with are given below.

Epidote-Biotite-Gneiss.

The most common gneiss in the belt of country immediately east of the Togo Range is a rock, medium to coarse in grain, well banded in the field, but not conspicuously so in hand specimens, grey in colour, and showing the constituent minerals distinctly. The texture varies from that of a coarse granite with porphyritic felspars, through a crushed rock showing eyes of felspar in a cataclastic groundmass to a fairly fine-grained granulitic type showing little trace of cataclastic structure in thin section. Where the plagioclase is saussuritized it is greenish in colour in hand specimen, and shows up distinctly against any potash felspar present, which is usually pink in tinge. Frequently, however, the plagioclase is clear and colourless. There is in many cases sufficient biotite present to give the rock a dark colour in patches and bands, but the darker and lighter bands do not differ from one another except in the relative proportions of light and dark minerals.

In thin section the rock is seen to consist of porphyroblasts up to half an inch in diameter of a felspar varying in composition in different places from albite to andesine, but usually about oligoclase, in a base consisting of crushed or strained quartz often showing mortar structure, smaller felspar individuals frequently of several kinds, and dark green biotite. Diablastic or sieve texture (including "secondary micropegmatite") is not very common, though seen in places. There is frequently a good deal of microcline in small fresh individuals, and sometimes a little orthoclase. The biotite is accompanied by, and frequently intergrown with, much epidote. Muscovite, hornblende, sphene, orthite, apatite, and iron ores are subordinate, but practically always present. Garnet was never seen. Typical sections are shown in Pl. VII, Figs. 1 and 2.

The plagioclase varies greatly in freshness. The smaller crystals are frequently clear and without inclusions, but the larger porphyroblasts are almost invariably either much saussuritized and very cloudy, or full of tiny crystals of epidote, zoisite and mica, probably betokening the complete recrystallization of the mineral. The quartz is usually full of tiny inclusions, giving it a spotted appearance. The biotite is brownish-green in colour and very irregularly developed. It has very few pleochroic haloes. In some places it is intergrown with muscovite, but the biotite is everywhere predominant. Hornblende is present only in very small amount usually. It is a soda-bearing variety, bluish-green in colour. Minerals of the epidote group are never absent and frequently equal the biotite in amount. The usual greenish pleochroic type is most abundant, but clinozoisite is also common. Practically in every section some brown orthite is present, always surrounded by either epidote or clinozoisite. Titanite is a very important accessory, usually in grains and

irregular patches, but in some places, around Palime for example, it is in large brown envelope-shaped crystals (108*a*, 84, 85)[1]. On the weathered surface it shows up in places as white leucoxene envelopes up to half an inch in length (85). Hubert[2] records large crystals of sphene in gneiss north of Savalou, in Dahomey. Iron ores are not abundant, but between Toji and Kpatave the gneiss was observed to contain numerous tiny octahedra of magnetite (516) (Fig. 1).

The above description summarizes observations on a number of rocks from the belt of country from Pode, via Ho, Palime, and Sodo, to Atakpame. The specimens vary much in appearance macroscopically, but are all similar under the microscope. In composition the rock appears to be dioritic and is almost certainly in every case of igneous origin. Von Ammon[3] describes a similar rock from Nyamassila, north of Atakpame. These rocks are also very like the granitoid gneiss described by Hubert[4] from Dahomey, in the eastern extension of the same region. He does not, however, mention any conspicuous development of epidote, which is so constant and so characteristic in the gneisses along the east side of the Togo Range.

Farther east still, the "harder gneisses" described by Falconer[5] from Northern Nigeria appear to be similar to those of Togoland. These latter also show the folded and foliated pegmatitic veins found in the Nigerian rocks. The recent work of R. C. Wilson[6] in Southern Nigeria gives valuable details regarding the rocks of the crystalline Metamorphic series in that region. The biotite-gneisses described above appear to correspond in many particulars with his division of "Striated and Ribbon-Banded Gneisses" (p. 33), but it is unwise at present to enter further into detail on this point.

Hornblende-Gneiss.

This is a less common type than the biotite-gneiss, and was only found in two localities along the foot of the Togo scarp, namely, between Atakpame and Amlame, and on the hills west of Toji.

In hand specimens the rock found above Toji (514 and 178) is a coarse-grained granitoid gneiss, greenish-grey in colour, with large pink microcline porphyroblasts up to half an inch in length along with clear colourless quartz and dense olive-green saussuritized plagioclase. There is no distinct banding visible. In thin section it is a granitoid aggregate of grey saussurite and fairly clear microcline

[1] Numbers in brackets refer to specimens and slides in the possession of the Gold Coast Geological Survey.

[2] H. Hubert, *Mission Scientific au Dahomey*, 1908, p. 482.

[3] L. von Ammon, "Zur Geologie von Togo und vom Nigerlande": *M. d. Geogr. Ges. München*, Bd. i, 1905, pp. 424–6.

[4] H. Hubert, op. cit., p. 481.

[5] J. D. Falconer, *Geography and Geology of Northern Nigeria*, pp. 117 et seq.

[6] R. C. Wilson, etc., "The Geology of the Western Railway, Section I": *Geol. Surv. of Nigeria*, Bulletin No. 2.

microperthite with quartz and subordinate hornblende. There is much epidote and a little muscovite, green biotite, and apatite. (See Pl. VII, Fig. 3.)

The microcline is fresh and characteristically twinned, but the plagioclase is so cloudy with saussuritic material as to be indeterminable. The quartz has many tiny inclusions, and is for the most part interstitial and much crushed. It also shows strain extinction. The hornblende is in irregularly developed crystals which fringe out at the ends into the felspar. The mineral is very patchy in colour, being very light green round the edges, with irregular patches of dark green in the centre. The epidote is in irregular patches and aggregates throughout the rock.

The hornblende-gneiss between Atakpame and Amlame (70) is composed of a much altered plagioclase, apparently oligoclase-albite, in fairly large crystals, accompanied by green hornblende, with subordinate quartz, titanite, brown biotite, apatite, and iron ore. No microcline is present. The quartz is interstitial and granular, with shadowy extinction. The hornblende is very patchy in colour, like that described above, and is associated with much epidote in large and small crystals. It suggests derivation from pyroxene in certain instances. Veins of epidote traverse the slide.

The hornblende-gneiss appears to be a variety of the more general biotite-gneiss, the only typical difference being the substitution of hornblende for biotite. In Dahomey Hubert [1] finds a similar state of affairs. The granitic hornblende-gneisses are comparatively rare, having only been found in the Gourma district.

Tremolite-Gneiss.

This type (72) found at the Dikube River between Amlame and Sodo, is an irregular sheared aggregate of albite in individuals up to a third of an inch in diameter, quartz, and tremolite. The tremolite occurs partly in fairly large crystals, some of them seen in cross-section, but there are also numerous small needle-like crystals in bunches throughout the rock. The felspar has well developed lamellar twinning and is in places rather cloudy. A little untwinned felspar may be orthoclase. The quartz is granular, sheared, and somewhat dirty in appearance due to tiny inclusions. This rock may be of sedimentary derivation. Falconer [2] describes tremolite-schists from Mori, in Borgu, and also from the Nassarawa tableland.

Biotite-Gneiss.

In the basin of the Amu, south of Atakpame, a type of gneiss occurs which is different from that of the Palime area (43, 47, 58) (Fig. 4). It is a medium-grained grey rock in hand specimens, frequently having small garnets (almandite) scattered through it, and in places showing porphyroblasts of felspar up to half an inch

[1] H. Hubert, op. cit., pp. 487-8.
[2] J. D. Falconer, op. cit., p. 114.

in length. In thin section it shows porphyroblasts of oligoclase in a somewhat granulitic (sometimes inclined to cataclastic) groundmass of quartz, oligoclase, orthoclase, and microcline, along with flakes of brown biotite, this last somewhat orientated in places and sometimes accompanied by and intergrown with muscovite. The garnets are small and not abundant. There are usually a few rounded grains of titanite, and some stumpy apatite crystals as accessories. In places there is a little micropegmatite. The felspar is fairly fresh and the porphyroblasts contain rounded inclusions of quartz. The quartz of the groundmass is spotted with tiny inclusions. Von Ammon [1] describes a hornblende-biotite-gneiss found between Noeppe and Badja, south-east of Assahun, which is similar in some respects.

A variety of this rock (59) on the banks of the Amu River at Lauuru shows much more muscovite than biotite and also much microcline. The quartz in this case also is full of tiny inclusions and liquid-filled cavities, the latter frequently with vibratile bubbles. The garnet shows brown decomposition borders.

Another gneiss with brown biotite (501) occurs near Bogame in the Dsawoe Valley. In thin section the rock is a fairly coarse-grained granitoid aggregate of quartz and andesine, with subordinate brown biotite. A little apatite, hornblende, and magnetite are associated with the biotite. The constituents are fresh and the rock does not appear to be much sheared. It is probably a quartz-mica-diorite.

Muscovite-Biotite-Gneiss.

This rock underlies the Matse-Taingbe portion of the Ho Range, and is exposed below the Togo quartzites on the hills above Matse (26, 495) (Fig. 5). In hand specimen it is a grey, foliated, coarse-grained, porphyroblastic rock showing light grey rounded porphyroblasts of orthoclase up to about half an inch in diameter, fairly close together, with the darker minerals round them. Calcite crystals filled with rutile show up as brown patches.

In thin section the porphyroblasts are seen to be clear and usually untwinned, and to contain many tiny crystals and blebs of biotite, muscovite, hornblende, and rutile, frequently collected in the central part of the crystal. There are also many patches of magnetite in the felspar. Round the orthoclase individuals muscovite and green biotite are intimately intergrown in long and frequently bent lamellæ, and are accompanied by small rounded crystals of apatite and by much calcite, this last frequently interstitial. There are also many patches of iron ore. Much of the calcite is clear, but many individuals are full of tiny brown rutile crystals, in some cases lying chiefly along the cleavage cracks, but in others seeming to fill the crystal completely. The biotite is greenish-brown, and has many pleochroic haloes. There is no quartz. The rock does

[1] L. von Ammon, op. cit., p. 447.

not usually show cataclastic structure in thin section, probably owing to the complete reconstruction of the original constituents. It might be the result of the intrusion of an acid magma into an argillaceous rock.

One variety (29) found east of the Ho Range has epidote in small laths taking the place of the muscovite. The proportion of biotite is larger. The felspar in this case is a plagioclase, apparently about oligoclase-andesine, but not showing twinning lamellæ, and the inclusions are larger, most of them being epidote and hornblende The crystals of this latter have a distinctly bluish tinge and are probably arfvedsonite.

Hornblende-Schist.

Dark green schistose rocks, medium to fine in grain and composed mainly of hornblende, with well-defined orientation of the crystals, are very common along the east side of the Togo Range in the Crystalline Metamorphic Series. Under the heading hornblende-schist are grouped various basic schistose rocks with hornblende as their chief constituent, but the different types may have been derived from quite different original rocks. Some, which have the schistose character less strongly developed, might perhaps be more correctly designated amphibolite, but it is unnecessary to go further into detail on such points, especially as in many cases the rock was only seen in one small exposure, and its relationship to the other rocks of the series is quite unknown. As regards the hornblende-schists as a whole, it is sufficient to note that they are quite closely associated with the gneisses described above, and in some instances the two rocks seem to alternate with one another.

In nearly every instance hornblende constitutes at least half of the bulk of the rock. It is usually accompanied by a mineral of the epidote group and by subordinate felspar. The rocks are in general highly reconstructed and do not show much trace of cataclastic deformation of the minerals.

An interesting type (9) occurs in Gold Coast Territory, a short distance north of the Volta ferry on the Kpong-Pode road. In hand specimen it is a dark-green schist with rough orientation of the chief constituents which are clearly visible to the naked eye. In thin section it is seen to be a medium-grained aggregate of green hornblende and colourless clinozoisite. There are numerous small idiomorphic crystals of almandite, mostly enclosed by the clinozoisite individuals, and a fair amount of interstitial quartz. Tiny amber-coloured rutiles are scattered through the rock. Neither the hornblende nor the clinozoisite is idiomorphic. They both occur as somewhat elongated crystals of about equal size, but the structure is sub-granulitic. In amount the hornblende appears to be slightly predominant. The clinozoisite is full of small crystals, including almandite, rutile and green hornblende. The quartz is granular and clear, with tiny speck-like inclusions. This rock is probably

the final result of metamorphism of a gabbro. A similar rock (8) near at hand shows large and very ragged clinozoisite individuals and rather less interstitial quartz.

A rock resembling the above type, but showing clear orientation of all the chief constituents in thin section occurs on the road from Lauuru to Amukpa, on the banks of the Amu River (60). In addition to hornblende and clinozoisite there is labradorite in grains up to 4 mm. in length, with subordinate quartz and a little chlorite.

A schist found a short distance west of Atakpame on the Palime road (68) shows elongated crystals of zoisite and green hornblende surrounding eyes of an untwinned felspar which appears by its refractive index to be labradorite. There is distinct orientation of the hornblende and zoisite individuals. The zoisite laths are much cracked transversely, and in many cases have numerous inclusions. The felspar also contains numerous tiny crystals of epidote and hornblende. (See Pl. VII, Fig. 6.)

Types consisting almost entirely of amphibole occur in some places. One, about 3 miles north of Awonhui on the Palime road (31), is a dark green fibrous-looking schist in hand specimen and proves in section to consist of hornblende in crystals up to half an inch or more in length, accompanied by some chlorite in sheaves. There are also some tiny zircons and a few pyrite cubes. The pleochroism of the hornblende is from yellow to bluish-green. Another rock found at Djeti near Amukpa (64) consists almost entirely of sheaves of actinolite with a very little clear interstitial quartz.

The hornblende-schist associated with the marble beds on the Chra River is a dark greyish-green fairly fine-grained rock in hand specimens (53), and the chief constituent is green hornblende in hypidiomorphic crystals up to 10 mm. in length, all lying in one direction. The other principal constituent is fresh labradorite which fills the spaces between the hornblende crystals. It is in some instances rather crushed. There is some quartz associated with the felspar. A fair amount of epidote is present as granules. Some grains like apatite in appearance may possibly be idocrase.

Between Amlame and the Amu River on the Palime road occurs a rock which probably represents an intermediate stage in the metamorphism of the rock type which has given rise to the epidote-hornblende-schist described above. It is a dark compact greenish schist in hand specimens (74) and is a sub-granulitic aggregate of green hornblende and epidote, with a little augite. There are cloudy grey patches which look like saussuritized felspar and crystals of zoisite into which the saussuritic material is apparently being converted. There is a good deal of magnetite in irregular patches. About 80 per cent of the rock is hornblende.

Another variety of hornblende-schist contains orthoclase (518), but this is uncommon. It is found to the west of Kpatave as a medium-grained greyish-green schist, sometimes with white speckling. The dip of the foliation planes is to the east at moderate angles.

The hornblende is in crystals up to 10 mm. in length and well orientated. Orthoclase is subordinate in crystals which are in places sheared round the edges, and quartz, epidote, muscovite, greenish-brown biotite, and chlorite are present, with a little titanite, apatite, almandite, chlorite, and pyrite as accessories.

In the Crystalline Metamorphic Series of Dahomey Hubert[1] has found types similar to those described above.

Hypersthene-Gneiss.

These rocks were found at several points below the eastern scarp of the Togo Range, and on Agu Mountain. They range in composition from quite silicic varieties to pyroxenites consisting almost entirely of monoclinic and rhombic pyroxenes. These last do not seem to have undergone appreciable metamorphism, and in one case at least are intrusive in rocks of the Togo Series, but it seems best to describe them here along with the igneous gneisses of which they are the ultra-basic members as far as composition goes.

Pyroxenites were found at three localities, namely, between Kwasikofe and Komlakofe on the road from Pode to Sokode, at Taingbe in the Ho Range and at Pheto, north of Akata on the road from Palime to Atakpame.

The rock at the first of these (19) (Pl. VIII, Fig. 7) is a holocrystalline aggregate of diallage and hypersthene in roughly equal proportions, both constituents being fresh. The diallage individuals are up to half an inch in length, allotriomorphic and practically free from inclusions. The hypersthene crystals are rather smaller, and hypidiomorphic in many cases. They contain numerous long thread-like inclusions, lying in two directions, at 60° to one another in sections perpendicular to the vertical axis and equally inclined to the directions of extinction. The mineral is strongly pleochroic in pink and green tints. Some of the diallage crystals are composite, having hypersthene intergrown with them in a perthitic manner, the hypersthene being shown up by its pleochroism and by the coarse cracks which traverse it. There is a fair amount of green hornblende in small grains between the diallage and hypersthene crystals. This mineral also appears in some of the composite diallage crystals, a large crystal of diallage containing streaks and patches of hypersthene and hornblende, all three minerals arranged with their vertical axes parallel. The Taingbe pyroxenite was not seen in situ, but the Wuta River yielded such abundant fragments of pyroxene, both monoclinic and orthorhombic, that the presence of the rock in the vicinity is practically certain.

A mile and a half north of Akata occurs a pyroxenite intrusion in the Togo quartzites. It forms a conspicuous rounded hill called Pheto, below the main Togo Range scarp. The summit of the hill is about 550 ft. above the average level of the country to the east. Along certain lines serpentinization has taken place to a small extent.

[1] H. Hubert, op. cit., pp. 486 et seq.

The shape of the intrusion in plan appeared to be roughly oval, as far as could be seen, with long axis north and south. The area covered is probably between $\frac{1}{4}$ and $\frac{1}{2}$ square mile. On the road east of this a Togo quartzite, dipping north at 30°, contains veins and patches of ilmenite, probably genetically connected with the intrusion. The quartzite is much sheared and sericitic.

In hand specimens the pyroxenite (182) shows the diallage crystals to be well orientated. In this locality the proportion of orthorhombic to monoclinic pyroxene varies greatly. The hypersthene is not so strongly pleochroic as in the case of the pyroxenite north of Pode. Much of the diallage shows pronounced lamellar twinning. Both diallage and hypersthene are practically free from inclusions and hornblende is absent. There are small patches of black iron ore. In other respects the rock resembles that north of Pode.

The ilmenite (80) found in the quartzite seems certainly connected with the neighbouring intrusion. The ilmenite-bearing rock shows irregular brecciated masses of ilmenite in much sheared quartz. There is much sericite, and many fine fibres of biotite are scattered through the rock, chiefly amongst the quartz grains. The ilmenite contains numerous tiny crystals which seem in most cases to be zircon. Some are distinctly zoned. In some cases, however, the crystals appear rather like pyroxene.

The more siliceous hypersthene-gneisses are chiefly from Agu Mountain, but an interesting rock was found at Sokode, on the Pode–Palime road (25). It is a medium-grained rock, granulitic in texture, consisting of plagioclase, hypersthene, augite, biotite, and quartz. About half the rock is plagioclase, with pyroxene, biotite, and quartz making up the other half in approximately equal quantities, the pyroxene predominating. (See Pl. VIII, Fig. 8.)

The quartz is well scattered through the slide and is sometimes in blebs up to 8 mm. in diameter, but is mainly interstitial. It is fairly clear, but with tiny inclusions and slightly strained. The felspar, which is andesine, shows lamellar twinning in most cases, though some of it seems untwinned. It is full of tiny short needle-like inclusions and shows slight cloudiness, like incipient saussuritization. The hypersthene and augite are like those in the pyroxenite described above, occurring between Kwasikofe and Komlakofe. The hypersthene crystals, which are frequently hypidiomorphic, are intergrown with greenish-brown biotite. With them is associated light-green monoclinic pyroxene and black iron ore, probably chiefly ilmenite. The hypersthene is in most cases fringed with greenish crypto-crystalline material, which is probably chloritic. As this rock appeared to have certain points in common with the intermediate members of the charnockite series as described by Holland, it was compared with specimens of these latter kindly lent for the purpose by Professor S. H. Reynolds. In hand specimen it is exceedingly like the norite associated with charnockite at

St. Thomas' Mount, Madras. In thin section it agrees well with some of the intermediate rocks of Professor Reynolds' suite in most points, except as regards the amount of biotite present, which is greater in the Togoland rock. However, the Indian specimens examined showed in the main a good deal more biotite than Holland's description would lead one to expect. Lacroix,[1] in describing charnockitic rocks from French Guinea, also notes that there are amongst them several varieties of norite pretty rich in biotite. The chloritic material fringing the hypersthene and filling cracks in it is rather like the delessite seen in the St. Thomas' Mount rock.

Agu Mountain seems chiefly built up of a hypersthene-bearing gneiss. In the field it is a highly foliated rock varying in grain from fine to coarse and showing all gradations from a rock with composition approaching that of gabbro to a highly metamorphosed garnetiferous hornblende gneiss. The strike of the foliation planes is usually N.N.E.–S.S.W.

One specimen (90) from between the peaks of Klete and Nungbetsetse is a medium-grained foliated rock in hand specimens, greyish in colour, with quartz, felspar, hypersthene, and garnet clearly visible. In section it is a somewhat sheared rock showing irregularly developed hypersthene individuals and shapeless garnet crystals in a rather cataclastic aggregate of quartz and felspar. The felspar shows practically no lamellar twinning, but by refractive index appears to be mostly labradorite. There are many needle-like inclusions due to incipient alteration prior to lateritization. Some of it shows a patchiness between crossed nicols, rather like that seen in sections of microcline making a small angle with the principal twinning plane, but in this case probably due to variation in composition of the felspar due to the development of garnet in the rock.[2] The quartz is full of tiny specks, but fairly clear. The hypersthene is strongly pleochroic in pink to green and is in most cases surrounded by secondary pale-green radiating sheaves of tiny crystals which appear to be amphibole. This in its turn is surrounded by a zone of small, nearly colourless garnets. Ilmenite and brown biotite are associated with the hypersthene, the biotite chiefly replacing parts of the hypersthene core, and in practically every case being accompanied by ilmenite. Some of the pyroxene does not extinguish straight and is rather brownish-grey in colour and slightly pleochroic. It is apparently a monoclinic variety though not the same as the greenish-grey augite which occurs in some others of the Agu rocks. The garnets are pale pink in colour, with only a few bleb-like inclusions. Some of these look like Carlsbad twins. Others may be quartz. The ilmenite is in many cases surrounded by a corona of small garnets similar to that round the hypersthene.[3] (See Pl. VIII, Fig. 9.)

[1] A. Lacroix, *Compt. Rend.*, vol. cl, 1910, p. 18.
[2] Cf. Stillwell, *Metamorphic Rocks of Adelie Land*, 1918, pl. viii, fig. 6.
[3] Cf. Stillwell, op. cit., pl. v, figs. 5, 6; pl. vi, fig. 1.

A rock from between the peaks of Sotui and Dukloto (94) is similar to the above, but rather lighter in colour in hand specimen and coarser in grain. In thin section also it is similar, but rather more granulitic in character. The felspar (labradorite) is much fresher, but full of tiny needles, and many of the crystals contain small, clear fusiform inclusions which are distinctly of lower refractive index than the felspar. There is also a little quartz, similar to that in (90). The hypersthene is more strongly coloured and so also are the sheaves of hornblende crystals which surround it. There is also some pale greenish-grey augite, cloudy with finely divided iron ore. The distribution and association of the hypersthene biotite and ilmenite are similar to that described above. The ilmenite has in places green hornblende fringes like the hypersthene. There are no large garnets.

Another rock (96) from the west side of the mountain, above Dalave, is a dark-grey hornblende-schist in hand specimens, heavy, and well foliated. It is medium in grain, showing felspar and ferromagnesian minerals distinctly to the naked eye. In thin section it is seen to be a basic rock with deeply-coloured, strongly-pleochroic hypersthene intergrown with brown biotite and associated with dark brownish-green hornblende, with very subordinate felspar and no quartz. There are well-defined coronas round the hypersthene and mica, apparently of hornblende, sometimes in needle-shaped crystals. The hypersthene is full of "schiller" inclusions. The felspar, which is mostly untwinned, is labradorite, judging from its refractive index. It is full of tiny needle-like inclusions. Iron ore is practically absent.

A similar rock from the southern flanks of the mountain (100) contains no biotite, and dark-green hornblende is the predominant constituent. There is a good deal of greenish augite, rather altered and black with iron ore, and the hypersthene can be seen in some instances half replaced by hornblende. Much of the hornblende is dark in the centre with iron ore. The felspar is labradorite, much of it untwinned. It has many tiny needle-shaped inclusions, and (?) incipient saussuritization is shown round the edges of the individuals forming cloudy bands between them and the other constituents. There is a little magnetite, apatite, and quartz, but no garnet. The quartz is fairly clear, but with many tiny inclusions. A rock very like this last, but without hypersthene —though it probably contained it originally—is found on the west side of Sotui peak, above Dalave (95) (Pl. VIII, Fig. 10).

One of the final stages in the metamorphism of the Agu noritic rocks is seen near Etoi on the south side of the mountain. Here a garnetiferous hornblende-gneiss (97) outcrops, showing small to medium-sized allotriomorphic hornblende crystals in a mosaic of felspar grains, and accompanied by pink garnet in small crystals. There is also much epidote and zoisite in small crystals scattered through the rock. No quartz was noticed in the section. The

felspar is not usually twinned and is clear and fresh in appearance. It seems by its refractive index to be andesine. The garnet is full of tiny bleb-like inclusions, some of hornblende and some possibly of quartz. There is a fair amount of greenish-grey augite partially replaced by hornblende. Iron ores are scanty.

The hypersthene-gneisses described above have so many points in common with the rocks of the charnockite series that it seems worth while to consider the point a little more in detail. Unfortunately there are no chemical analyses to assist in the comparison. Taking then the different minerals present we find the following points.

Quartz.—This has in some cases, though not in all, the bluish tinge described by Holland,[1] and is seen in section to be full of tiny spot-like inclusions. No rod-like bodies are to be seen. The spotting in the Togo quartz is similar to most of that seen in Professor Reynolds' specimens.

Felspar.—No acid rocks comparable with charnockite itself were found, and microcline was not seen in any of the specimens. The common absence of twinning lamellæ in the plagioclase felspar is a point of resemblance. This is noted in the Indian rocks by Washington.[2] Fusiform inclusions of quartz in the felspar have been referred to above. Holland[3] and Washington[4] only note their occurrence in the more acid felspars, in which they show up as bodies having a refractive index higher than that of the felspar. In many cases in the Togo slides, and in many of the slides in Professor Reynolds' collection, the felspar containing the inclusions has a higher mean refractive index than quartz, and the inclusions show up as bodies with lower refractive index than the surrounding felspar.

Hypersthene.—This mineral is like that of the Indian specimens both in composition and in development. It is distinctly pleochroic; *a* and *b* light red or pink, *c* pale green or blue-grey. As noted by Holland (op. cit., p. 160) the pink colour of the hypersthene is so like that of the garnet that they might at first sight be confused with one another. None of the Indian specimens examined exhibits alteration of the hypersthene round its edges to a pale green amphibole as described above in the Agu rocks. Holland, however (op. cit., p. 161), records garnet forming coronas round hypersthene crystals. At Agu, however, there is no regular development of quartz between the garnet corona and the hypersthene core. In a paper by Holland, however, on "The Origin and Growth of Garnets",[5] coronas analogous to those in the Agu rocks are described in rocks from Bengal. No development of delessite along cracks in the hypersthene and around

[1] T. H. Holland, "The Charnockite Series": *Mem. Geol. Surv. India*, vol. xxviii, pt. ii, 1900.

[2] H. S. Washington, *Amer. Journ. Sci.*, vol. xli, April, 1916, p. 336.

[3] T. H. Holland, op. cit., p. 140.

[4] H. S. Washington, op. cit., p. 326.

[5] T. H. Holland, *Rec. Geol. Surv. Ind.*, vol. xxix, p. 20.

the crystals, similar to that which characterizes the specimens from St. Thomas' Mount, was seen in the Agu rocks. As noted above, however, it occurs in the rock from Sokode.

Augite.—Besides the hypersthene there is present a monoclinic pyroxene very like it in colour and pleochroism, but paler, with distinctly oblique extinction. A similar mineral is described by Washington (loc. cit., p. 335) as occurring in some of the Indian rocks. In addition to the above there is a greenish augite in the Agu rocks, non-pleochroic and frequently containing many specks and patches of iron ore.

Garnet and *Biotite* are similar in the Togo and Indian rocks.

The texture of the Togo rock is predominantly granulitic, in which character also it resembles the Indian rock.

A rock from Toro, in Bauchi province, Northern Nigeria, is described by Falconer [1] as having a certain affinity with the rocks of the charnockite series. The Togoland occurrences lie midway between Toro and N'Zo on the Ivory Coast, where the charnockitic rocks described by Lacroix [2] occur.

Von Ammon [3] mentions a hypersthene-gabbro found by von Seefried between Bafilo and Semere in N.E. Togoland. This may perhaps belong to the same family as the rocks described above.

Gabbro.

A rock seen in the bed of the Labo River, in the Dsawoë Valley, though somewhat banded in the field, is not appreciably so in hand specimens (497). It is a coarse-grained granitic aggregate of white felspar, partly porphyritic, with green hornblende and dark brown biotite. A little quartz is also visible. As seen in thin section the felspar, though nearly all untwinned, is probably by its refractive index a labradorite and is somewhat saussuritized. It is associated with augite, always largely and in some cases completely uralitized, and with brownish green biotite. This last has much black iron ore throughout it. There is a little interstitial quartz. Similar rocks appear to underlie a large part of the Dsawoë Valley.

Garnet-Amphibolite.

This has been referred to as eclogite by Koert, but as all the specimens examined contain a large amount of hornblende, and as pyroxene is in most cases quite subordinate, the name garnet-amphibolite is more suitable. It is well developed in a belt of country trending N.N.E.–S.S.W. to the west of the road between Tokwe and Nyive. Its extent was not determined, but it was crossed on the Nyive–Ave road and also on the Ave–Tokwe road, and is probably continuous between these two points.

In hand specimen it is usually a coarse-grained, foliated, mottled

[1] J. D. Falconer, op. cit., p. 138.
[2] A. Lacroix, *Compt. Rend.*, vol. cl, 1910, p. 18.
[3] Op. cit., p. 437.

green and pink rock, frequently showing large crystals of pale hornblende and epidote accompanied by garnet. In places, however, it appears as a medium-grained dark green amphibolite, whilst in some specimens it is more granulitic in character and unfoliated. Under the microscope the chief constituent is usually a pale green hornblende, sometimes in large almost idiomorphic crystals, accompanied by epidote and garnet with rather subordinate diopside and sometimes some quartz.

One rock (34) near Tokwe shows crystals of pale green hornblende and of clinozoisite up to 15 mm. in length in a groundmass of small hornblende and garnet crystals, the whole somewhat sheared. In places the large clinozoisite crystals are arranged radially in groups. They enclose small rutiles and garnets. The hornblende also encloses the same minerals. There is a little interstitial quartz, but no pyroxene.

Another type (489) found between Nyive and Ave is composed of green hornblende in individuals of all sizes and garnet, with subordinate diopside and calcite. Quartz is absent in this case. The hornblende crystals contain many rutile, garnet, and epidote inclusions. The diopside is pale green in colour and also contains numerous inclusions. The garnet is pink in colour and in very ragged crystals.

One variety on the Ave–Tokwe road (494) (Pl. VIII, Fig. 11) shows green hornblende, clinozoisite, diopside, and clear well-formed garnets in thin section. The clinozoisite is in large lath-shaped crystals, whilst the hornblende and diopside show no definite form. There is a little quartz present, and brownish-yellow rutile in small crystals. There are also some dense cloudy aggregates of small crystals, probably amphibole, chiefly surrounding the pyroxene individuals of which they are the alteration product.

Rocks in some measure corresponding with the above amphibolites are recorded by Hubert (op. cit., pp. 488–9) from Tchaourou and Djougou in Dahomey.

Dolerite.

Amongst the basic intrusive rocks found in the Dsawoë Valley are two dolerites, one a fragment found at Bogame and another north of Safiefe. They appear to be quite similar in type in thin section. That at Bogame (500) is a fairly coarse-grained rock in hand specimens, showing laths of greenish saussuritized felspar with a dark ferromagnesian base and tiny pyrite specks. In structure it is subophitic. The felspar is much saussuritized; and the augite, which is a purplish titaniferous variety, is to a great extent uralitized. The secondary hornblende is dark brown, but is in many cases green round the edges of the crystals. There is a fair amount of ilmenite, partially altered to leucoxene.

The other rock (508) is rather finer in grain. The felspar is somewhat fresher and occurs as laths showing lamellar twinning.

By refractive index it appears to be labradorite. The augite is pale brown, hypidiomorphic, and in nearly every case twinned. It is uralitized round the edges of the crystals and has also a large amount of brown hornblende along the cleavage planes, though some of this latter may be biotite. There is also much magnetite, surrounded by secondary green hornblende.

Between Komlakofe and Kwasikofe, near the south end of the Ho Range, a rock in hand specimens like an altered dolerite was found, and a rather similar type of rock occurs a short distance north of Awonhui, between Ho and Kpatave. The first of these (18) has a dark brown crust and shows lath-shaped felspars in a dark matrix. The second (30) (Pl. VIII, Fig. 12) has a pink tinge, due to the abundance of garnet in it.

In section they show highly uralitized crystals of augite in a base of felspar crystals studded plentifully with small garnets. The cores of the augite crystals are light brownish-green in colour and non-pleochroic. The margin, and sometimes the whole interior, of the crystal is altered to small crystals of greenish-brown pleochroic hornblende. The augite cores are in many cases dusty and much cracked. The felspar is not much twinned and appears to be about oligoclase-andesine in composition. It contains in places a fair number of small epidote crystals, but is not cloudy. There are a good many patches of magnetite, surrounded by brown biotite. Some of the felspars contain long needle-like crystals, possibly of tremolite. The garnets are colourless in thin section, and fresh to somewhat decomposed. Although it is not clear what type of original rock the above specimens represent, they are described here with the dolerites, as it is with them that they seem to have most in common. Dolerite intruded into the rocks of the Crystalline Metamorphic Series, and metamorphosed along with them would probably, under certain conditions, give rise to such rocks.

Under the microscope a fine-grained dark slaty schist (498) seen cutting through the gabbro in the channel of the Labo River, in the Dsawoë Valley, is somewhat similar. It shows green hornblende and brown biotite with much iron ore, accompanied by a fair amount of felspar. The felspar, which appears to be labradorite though not much twinned, contains a fair number of tiny zoisite and hornblende crystals as inclusions, but is not cloudy. The hornblende appears partly at least to be derived from pyroxene, as it occurs largely as fibrous clusters of tiny crystals. There may be a little interstitial quartz. The rock may be termed a hornblende lamprophyre.

Serpentine.

South of Amukpa, on the south side of the Amu, a line of conical topped hills runs north and south, and the most northerly of these is composed of serpentine, with chromite. This is apparently an intrusion in the gneisses of the Crystalline Metamorphic Series.

A portion of the east side of the hill is composed of massive quartzite. The rest appears to be serpentine, greenish to yellowish in colour and accompanied by much talc, and here and there common opal in veins. The chromite-bearing area is on the north-east slope and does not appear to occupy more than an area 50 to 100 feet square.

In section the serpentine rock (61) is seen to be an irregular mixture of serpentine and talc, and it shows no residual mineral to indicate from what type of rock it was derived. Certain antigorite pseudomorphs, however, appear by their shape to indicate original augite crystals. The bulk of the rock, however, shows a mesh structure, and it is likely that the parent rock was a peridotite with subordinate pyroxene. There is a little chlorite present, and a fair amount of very fine powdery chromite is scattered through the rock, some of it in elongated particles along the talc cleavage planes.

Where the chromite is concentrated, however, its chief associate is chlorite (62, 63). The chlorite is of two kinds, namely, clinochlore, which is greenish in hand specimen, and kotschubeite, a chrome-bearing variety which is of a fine violet colour. The chromite-bearing rock consists of a fibrous matting of these chlorites in which are embedded chromite crystals and crystal fragments. The chromite is partly brown and translucent, but for the most part black and opaque. The crystals are much broken and cracked, the cracks being filled with chlorite. In other specimens there is a good deal of quartz present, whilst yet others show much talc along with the chromite.

Marble.

This rock was found in the bed of the Chra River, south-west of Glei. The district is for the most part composed of the biotite-gneiss described above, the planes of foliation in the gneiss being nearly vertical with strike N.E.–S.W.

Three exposures of marble were observed, all in the stream channel. The main bed is about 55 feet thick with a dip of 79° to the N.W., and crosses the river-course obliquely. It is greyish-white in colour, tough, of even texture, and shows definite planes of jointing. It is nearly pure, but has subordinate tremolite in some places. The second bed is about 100 yards farther up the river, and the exposure in this case measures 20 feet across the outcrop, the dip being over 80° to the S.E. The marble is similar to that in the main bed. Several blocks found near here have much tremolite in them, as crystals scattered throughout the marble. The intervening strata are hornblende-schists showing the same direction of strike as the marble, but too much contorted to give a definite dip for the foliation-planes. The third exposure is some 50 yards higher up the stream than the second, and is only poorly shown. It is the same as the other beds in quality and appearance. The strata between the second and third beds are not exposed.

The purer type (51) is white to pale blue in hand specimen, and is a granular aggregate of clear, non-interlocking crystals of calcite averaging 6 to 8 mm. in diameter. As scanty accessories there appear small apatite crystals, bent mica lamellæ, crystals of tremolite, and a little rutile.

The more impure type (55) is white in hand specimen, with orientated yellowish tremolite laths scattered through it. In section it is similar to the other and also shows mica, apatite, and rutile as accessories. On dissolving a little of the marble in hydrochloric acid the residue was found to be mainly phlogopite in tiny flakes. The crystalline limestone bands recorded by Falconer[1] from Igbo in the Bassa Province of Northern Nigeria appear to be similar to the Chra River ones in having tremolite as the chief impurity.

Summary.

1. A belt of gneiss of dioritic composition lies along the west side of the Togo Range, and is exposed at intervals practically all the way from Pode to Atakpame.

2. Associated with it are hornblende- and mica-schists, garnet-amphibolites, and hypersthene-gneisses resembling rocks of the charnockite series. These last form the greater part of Agu Mountain, and also occur at several places along the foot of the Togo scarp.

3. The valley of the Dsawoë River appears to be in large part underlain by gabbro and dolerite types of rock, with associated dyke rocks.

4. A tract of garnetiferous biotite-gneiss, partly granitic in composition, occupies that part of the basin of the Amu River due south of Atakpame. It is associated with schists similar to those accompanying the dioritic gneiss.

5. Basic intrusions occur in the gneisses, e.g. serpentine at Djeti and pyroxenite north of Pode. A pyroxenite north of Akata is intrusive in rocks of the Togo series. No granitic intrusions were found.

6. The rocks described form a basement upon which the rocks of the Togo series and other younger ones rest.

Acknowledgment is due to Mr. A. E. Kitson, Director of the Gold Coast Geological Survey, under whose direction the field-work was done, for the use of slides and specimens, and also to Professor S. H. Reynolds for the loan of his set of slides and specimens of rocks of the charnockite series.

EXPLANATION OF PLATES VII AND VIII.

Approximate positions in the figures are indicated by points of the compass and decimals of the distance from centre to circumference; thus N.E. 6 indicates a position six-tenths of the distance to the circumference in a N.E.

[1] J. D. Falconer, op. cit., p. 82.

direction from the centre of the figure. The magnification is in every case 18 diameters.

Fig. 1.—(516.) *Epidote-Biotite-Gneiss.* Large porphyroblasts of fairly clear, almost untwinned oligoclase, one occupying practically the whole of the S.W. quadrant, are surrounded by irregular patches of green biotite (N. 9, E.N.E. 4, etc.) accompanied by epidote (N. 2 and S.E. 1), titanite (N.E. 1 and S.S.E. 2), and irregular grains of clear quartz. A dark-brown orthite crystal enclosed in one of epidote is also shown (N.N.W. 3). A little calcite is present (E. 5).

Fig. 2.—(77.) *Epidote-Biotite-Gneiss.* The N.W. quadrant shows a crystal of saussuritized felspar with dense cloudy patches. The E. side of the field of view is of quartz, showing mortar-structure under crossed nicols, and full of tiny dark specks. The S.W. quadrant shows a good deal of dark-green biotite in part intergrown with chlorite. Granular epidote is present in fair amount round the centre and to the S., whilst a dark-brown titanite crystal is also to be seen (S.W. 10).

Fig. 3.—(514.) *Hornblende-Gneiss.* Dense saussuritized plagioclase is shown on the W. side of the field and just E. of the centre. On the E. margin is a portion of a microcline individual, somewhat cloudy but not so dark as the plagioclase. Just W. of it is a strip of granular epidote and clear quartz, which forms a thin vein traversing the rock. A larger patch of quartz is shown in the N.W. quadrant. Between the two larger plagioclase crystals lie smaller ones intergrown with hornblende (N. 3, W. 3, etc.), which is very patchy in colour, the central portions of the individuals being dark green, whilst the surrounding parts are very pale green and have ragged edges.

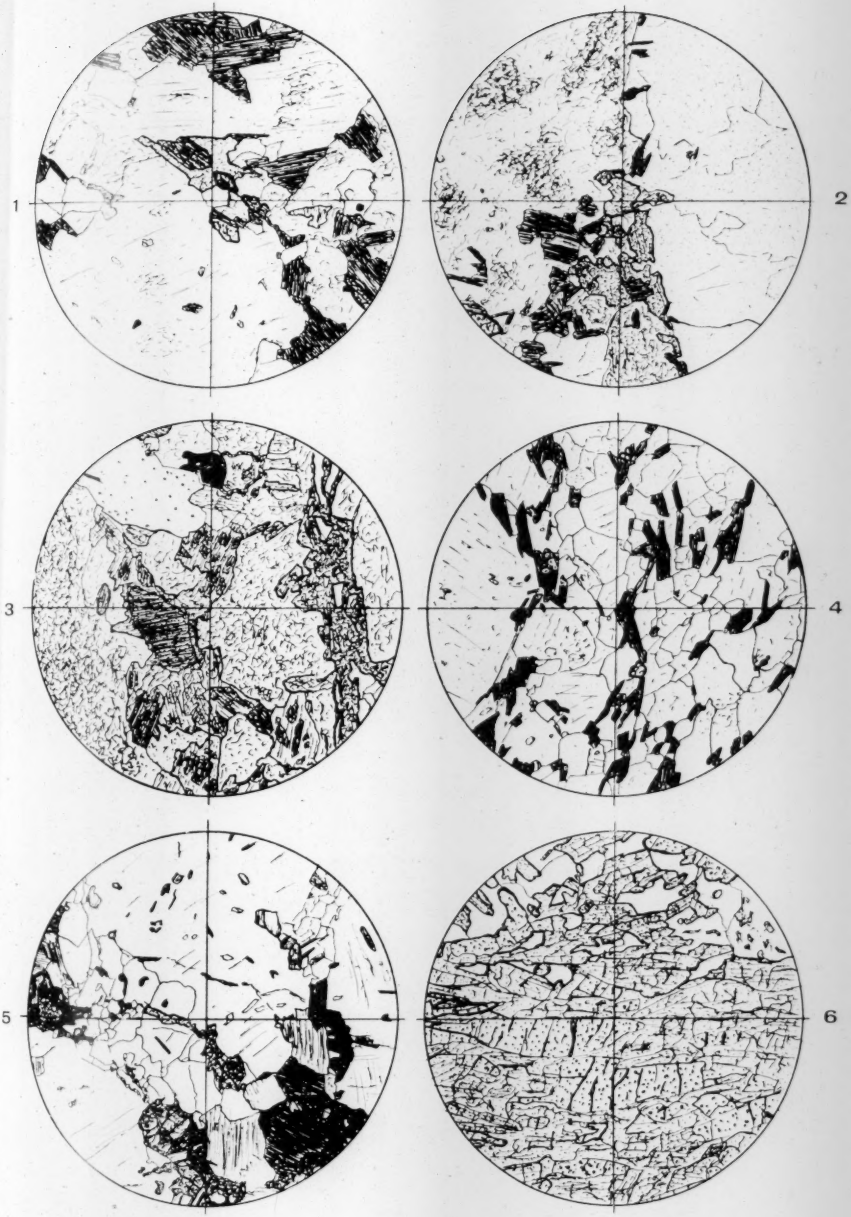
Fig. 4.—(47.) *Biotite-Gneiss.* A large clear crystal of albite-oligoclase on the W. of the field is typical of the porphyroblasts in this rock. The groundmass is a mixture of fairly well orientated brown biotite with clear microcline (N. 5, S.S.W. 5, etc.) and quartz (N.N.E. 10, S. 3, etc.), and a little plagioclase similar to the porphyroblasts. A garnet crystal is also shown (S.S.E. 3).

Fig. 5.—(495.) *Muscovite-Biotite-Gneiss.* Large orthoclase individuals, one nearly filling the N. portion of the field, another on the E. side, and a Carlsbad twin in the S.W., are associated with much muscovite and greenish biotite (S.E. quadrant) and with calcite. This last (W. 9, S.S.W. 6, and a large patch surrounding biotite in the S.E.) is in many instances so full of tiny rutile crystals as to be opaque. The orthoclase is clear, but contains many tiny biotite, muscovite, and rutile inclusions. It is accompanied by small microcline crystals (N.W. 2, etc.). There is no quartz present.

Fig. 6.—(68.) *Zoisite-Hornblende-Schist.* Ragged, transversely cracked laths of zoisite (W.S.W. 2, S. 4, etc.) lie in a similarly orientated mass of green hornblende crystals. Both have many inclusions. These occupy the whole of the S. half of the field. A labradorite crystal with numerous inclusions of hornblende and zoisite is shown in the N.E., whilst in the N.W. quadrant are many patches of clear quartz.

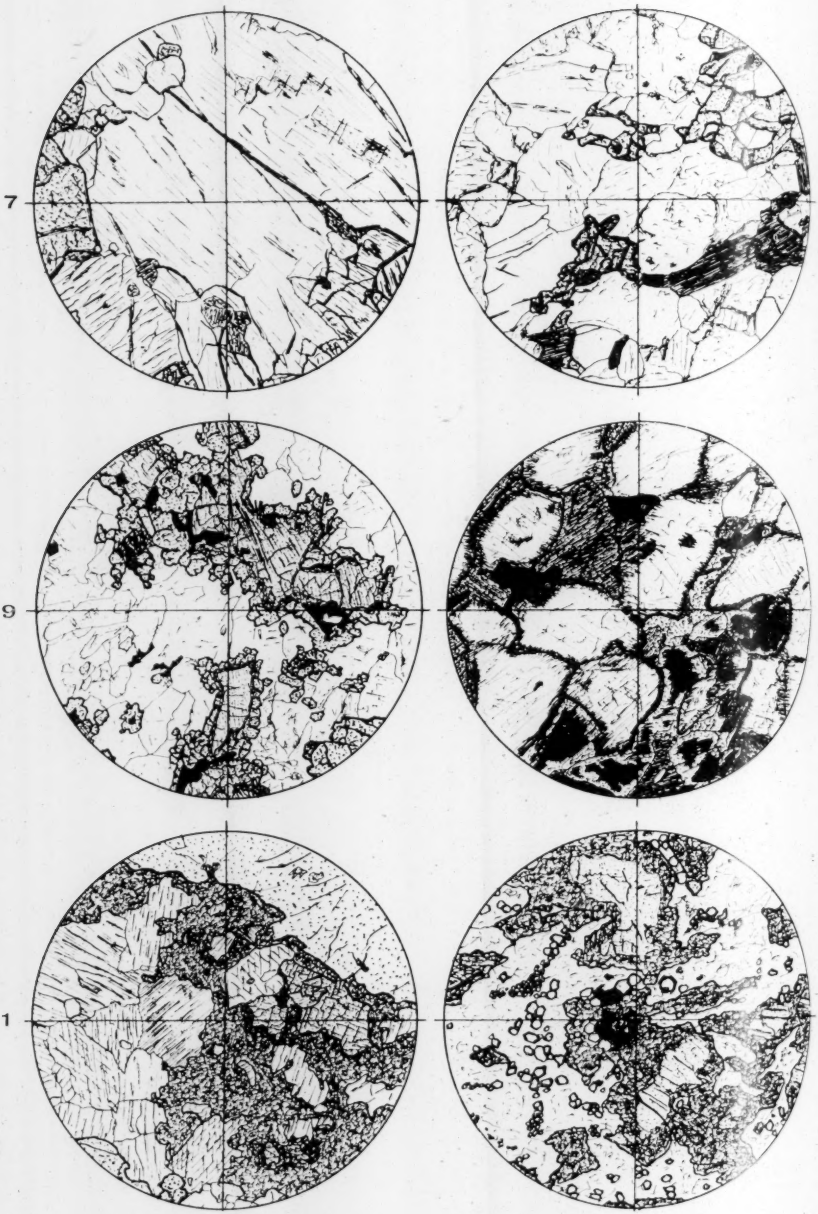
Fig. 7.—(19.) *Pyroxenite.* Diallage is the chief constituent in the field of view. Two large crystals lie side by side, one in the centre and the other in the N.E. quadrant. The latter shows by transverse cracks and by more pronounced cleavage where it is intergrown with hypersthene and hornblende respectively. Hypersthene crystals (W. 8, W.N.W. 10, and N.N.W. 8) are on the whole better formed than the diallage ones and in places are idiomorphic. One (W. 8) shows tiny rod-like bodies lying in definite directions within the crystal. Hornblende is in fair quantity interstitially (S.W. 5, S. 6, etc.), as well as intergrown with the diallage.

Fig. 8.—(25.) *Hypersthene-Gneiss.* The quartz (N.W. 7, W.S.W. 6, etc.) is clear but with numerous tiny spots. It is in irregular individuals and much cracked. The hypersthene (N.E. 7, N.N.W. 3, S.W. 3, etc.) is hypidiomorphic, in small weakly pleochroic individuals veined in some



ROCK SECTIONS, CRYSTALLINE METAMORPHIC ROCKS OF WESTERN TOGOLAND.

[To face p. 131.



ROCK SECTIONS, CRYSTALLINE METAMORPHIC ROCKS OF WESTERN TOGOLAND.

To face p. 135.]

cases (S.W. 3) with delessite or some similar chloritic mineral. It is in nearly all cases accompanied by and often apparently grown upon iron ore. Brown biotite (S.E. 5, etc.), very patchy in appearance, is also present in considerable quantity. Some of the pyroxene (e.g. E.N.E. 6), though similar in appearance and pleochroism to the hypersthene, has distinctly oblique extinction. A small crystal of non-pleochroic greenish augite is to be seen just N. of a biotite individual (S.S.W. 8). Irregular granular andesine individuals occupy most of the rest of the field of view.

Fig. 9.—(90.) *Garnetiferous Hypersthene-Gneiss.* Irregular pyroxene individuals (N.E. 4, S. 5, etc.) are surrounded by a narrow band of secondary amphibole in tiny crystals, outside which is a fringe of nearly colourless garnet crystals. Larger pale-pink garnets also occur (S.E. 10). Dark patches of ilmenite (E. 5, etc.) are almost invariably associated with the altered hypersthene crystals, and usually they themselves have garnet fringes (S.E. 5, S.W. 7). Some of the pyroxene (E.N.E. 5), although showing the pleochroism of hypersthene, appears to have oblique extinction in longitudinal sections. A cataclastic aggregate of labradorite and quartz occupies the rest of the field, the felspar in some instances containing fusiform inclusions of quartz.

Fig. 10.—(95.) *Hornblende-Gneiss.* A granulitic aggregate of green hornblende (N.W. 4, S. 10, etc.), greyish-green augite (S.S.W. 9, S.E. 4, etc.), labradorite (W. 3, N. 8, etc.), and quartz (N.E. 8), with much iron ore (N. 5, etc.). The felspar is much saussuritized round the edges—probably the first step in the process of lateritization. The augite is very dark in the centres of the individuals, and appears to be in process of conversion into hornblende.

Fig. 11.—(494.) *Garnet-Amphibolite.* A large individual of clinozoisite occupies the N.E. part of the field, whilst another is seen in the S.W. corner. Irregularly developed grass-green hornblende crystals compose most of the W. side, whilst some pale greenish pyroxene is present (E. 3 and 6). This last is in process of conversion into amphibole, the crystals being eaten into by dense saussurite-like amphibole aggregates which cover a large part of the field of view and are densest immediately round the pyroxene. A little garnet is also to be seen (S.S.W. 9).

Fig. 12.—(30.) *Garnet-Amphibolite.* Large individuals of pale-green augite (N. 6, E. 8, and S.E. 4) are partly uralitized. Laths and irregular individuals of oligoclase-andesine studded with tiny garnet crystals occupy most of the remainder of the field. A patch of iron ore in the centre is surrounded by brown biotite.

REVIEWS.

THE CONCEALED MESOZOIC ROCKS IN KENT. By G. W. LAMPLUGH, F. L. KITCHIN, and J. PRINGLE. Memoirs of the Geological Survey, England and Wales. 1923.

THE authors are to be congratulated on the successful completion of an excellent task, worthily begun twelve years ago by two of them (G. W. Lamplugh and F. L. Kitchin) in the memoir "On the Mesozoic Rocks in some of the Coal Explorations in Kent" (Mem. Geol. Surv., 1911). This first work dealt with the rocks penetrated in the borings at Dover, Brabourne, Pluckley, and Penshurst. In the new memoir no fewer than thirty-nine colliery shafts and exploratory borings are discussed, in which rocks newer than the Coal Measures were passed through, most of them clustered in the south-east of Kent. The previous account could thus be supplemented and the subject treated much more fully; but it is pointed out that none of the borings described in the present memoir showed such a complete succession of Mesozoic formations as was found in the Brabourne boring. The section at that place, described in the earlier work, remained "the best index to the sequence below the Gault in Kent". It may surprise many to find that the table of formations in that county is almost complete from the Tarannon to the Pliocene.

A general account of the stratigraphy, illustrated by diagrammatic sections, deals with the underground structure of the area. This is described as very different from the surface structure, the dominant factor being the wedge-like arrangement of the Lower Cretaceous and Jurassic rocks as a whole. We are told that while the Palæozoic floor rises steadily northward, the base of the Upper Cretaceous formation (here taken to include also the Gault) sinks in that direction, and these two planes come nearer and nearer together, until in the northernmost borings described they are almost in touch. The causes of this remarkable wedging out of the intervening strata are discussed, also the result, which is of economic consequence; and it is pointed out that previous conceptions of the geology of Kent have been profoundly affected as a result of the borings. We may quote from the work that "now Kent was found to possess a fuller sequence, from the Eocene downward, than is known to occur in any other part of England, and besides had a range of Palæozoic strata not yet completely ascertained, but certainly including representatives of at least three different systems—Carboniferous, Devonian, and Silurian. The collections of fossils obtained from nearly all the members of this great sequence of systems contribute to make the palæontology of Kent as varied and full of interest as its stratigraphy".

The stratigraphical chapter is followed by a full and in all respects excellent account of the various borings, mostly with fossil lists

and valuable palæontological notes. There is, of course, little or no information concerning the Coal Measures. Nevertheless, the memoir is also of great economic importance in view of the further commercial development of the Kent coalfield.

The final clearly and concisely written chapter, occupying the last fifty pages of the book, deals with the faunal aspects and correlation of the strata. In it will be found a great deal that is of interest to the student of Mesozoic stratigraphy. The conclusions are based on minute and careful palæontological work. In the case of the Kimmeridge Clay, this is strengthened by fossil evidence from other localities, and the "Table of Zones of the Kimmeridge Clay in the Type Area (Dorset) and in Kent", which forms a very valuable addition to this summary of conclusions, is striking testimony to the value of modern zonal palæontology. An important formation like the Kimmeridgian is very inadequately represented by the two or three "zones" of our textbooks. Only a beginner, however, would assume that even the detailed palæontological sequence given by the authors in the memoir here reviewed is final and not an attempt at interpretation of a complex series of beds, based merely on present knowledge. Some of their identifications, and perhaps even the order of their zones, may need correction, and the number of the latter will certainly be increased when the extent of the beds laid down during the Kimmeridgian period is more fully known. The rapid advance in geological science, as in other branches of knowledge, may seem a little disconcerting to many, and no doubt it becomes increasingly difficult to keep up with the progress. But modern zonal work, still generally misrepresented as a mere splitting up of, instead of an adding to, the already known, will now have to be taken as a matter of course, however "annoying" it may prove to some writers of stratigraphical textbooks.

Very few errors have been noticed. *Aulacostephanus contejeani* (plate ii, p. 224) is Thurmann's not Salfeld's species; and *Macrocephalites* cf. *compressus* (Waagen) (p. 157) (*Macrocephalites* cf. *compressum* on p. 69) may refer to either *M. compressus* (Quenstedt) or to *M. subcompressus* (Waagen). Also *Gravesia* is recorded on p. 44 from a depth of 934 feet, about 200 feet below its horizon. We draw attention to these in no spirit of cavilling; and it will be seen from what has been said that we consider this memoir to be a magnificent record of a very important piece of work.

The Mineral Resources of Greenland. By Sydney H. Ball. Meddelelser om Grönland, vol. lxiii. 1923. pp. 1–60.

From the geological and mineralogical point of view there are two features of outstanding interest in the mineral occurrences of Greenland: the cryolite of Ivigtut and the native iron of Disko. Numerous other ores are found, though not in important quantity, while graphite also is fairly abundant and there are workable coal-

seams. The memoir here reviewed contains details of all known deposits of economic interest.

The cryolite of Ivigtut, the only known workable source of this rare mineral, is one of the most remarkable petrological phenomena of the whole world. It is essentially a pegmatite, but a pegmatite of extraordinary composition. It is of especial interest as giving the clearest proof of the magmatic origin of such minerals as pyrite, auriferous chalcopyrite, blende, argentiferous galena, and most curious of all, siderite. All of these occur in typical pegmatitic intergrowth with quartz, felspar, and mica, as well as the ore-minerals more usual in similar circumstances, such as cassiterite, molybdenite, wolfram, columbite, and fluorspar. The ore-body, which has the general form of a boss, is derived either from a granitic or, less probably, from a foyaitic magma.

The native iron of Ovifak and other localities has been frequently described, and is generally believed to be due to reduction of basalt by coal-seams : it may, however, be of direct magmatic origin, without reduction by carbon.

Graphite is very widely spread in Greenland, though not anywhere in important quantity. It occurs in a number of different ways : in basalts and pegmatites ; disseminated in granite-gneiss and in limestone ; as graphitic schists and shales, and in tabular and irregular masses, or in vein-like bodies, sometimes in shear zones.

Coal occurs at a large number of localities on Disko Island and the Nugsuak peninsula, in strata ranging without a break from Lower Cretaceous to Miocene. The best seams appear to be Upper Cretaceous. The coal is mainly a rather low-grade lignite, with about half the calorific value of Welsh coal, and very high ash. The Colonial mine at Kaersuarsuk, however, yields a rather better quality of sub-bituminous coal. The total output only amounts to a few hundred tons per annum, consumed locally.

Asbestos, mica, and a variety of semi-precious and ornamental stones are also reported, and some may eventually prove to be of value.

REPORTS AND PROCEEDINGS.

Edinburgh Geological Society.

21st November, 1923.

1. "The Rocks between Leith and Granton." By David Tait.

The rock section exposed between tide marks at Wardie consists, in great part, of shales with ironstone nodules. They have an easterly dip, but at the eastern breakwater of Granton Harbour they roll over and dip west. In this series of beds, at a point 300 yards east of the eastern breakwater, a three-foot coal crops out from under a one-foot limestone. It is not well exposed, as it has been dug all along its outcrop. The old workings in this coal were exposed when the railway was being made, and later, were laid

bare at the back of Wardie Hotel. As the beds roll over here with a westerly dip, the outcrop must go seawards again in the eastern half of the harbour. In the western half of the harbour the dip changes again to the east; and west of the western breakwater the coal seam is found again under the limestone. This outcrop was found after a close and careful search.

2. "Historical Notes on the Working of the Wardie Coal." By David Tait, H.M. Geological Survey.

The earliest record found of the working of this coal refers to the outcrop a mile to the west of Wardie, on the west side of Granton Harbour at Caroline Park and Pilton. The record is a charter dated 18th February, 1580, confirmed by James VI. at Holyrood House. It is the charter of John Melville of Carnaby, renting to Andrew Logan, an inhabitant of the town of Leith, the eastern half of the lands of Granton, with salt pans, coal mine, etc., lying between Granton Burn and Wardie Burn, for an annual rental of 100 marks. Later, in 1794, Wood, in his "History of the Ancient and Modern State of the Parish of Cramond", and in the [Old] "Statistical Account" (which he also wrote) he says: "A pit was sunk and machinery erected in Pilton Wood in 1788, but abandoned directly on account of the badness of the coal." The vestiges of several mines are still to be seen in the links of Broompark.

On the eastern outcrop of the coal at Wardie are the following records. The earliest I have found is that given in a book called the "Hydrostaticks", by George Sinclair, and published in Edinburgh, in 1672. In it, while writing about "Wildfire" in pits, he says: "The place where this was most known was in a coal mine west of Leith, in a piece of land called Werdy, which, for want of level, and violence of that fire, the owners were forced to abandon."

At Wardie, during the years 1831–1839, attempts were made to work this coal by Captain John Donaldson Boswall, of Wardie, and a mining tenant of his. But operations ended in a lawsuit and loss. This is the last attempt to work the coal at Wardie.

The poor quality of the Wardie Coal accounts for it not being worked at the present day. There is little doubt it was used chiefly to evaporate sea-water for the manufacture of salt.

At the date of the signing of the Charter of 1580, it is most interesting to note the close connexion existing between the manufacture of salt and the mining of coal. Professor Hume Brown, in his "Scotland in the Time of Queen Mary", says: "In Mary's time one of the sights which surprised our visitors was the multitude of salt pans which they passed on their way to the capital." Salt was truly a national industry, equally from the number of persons it employed and from the amount of wealth it brought to the country. The principal seats of the industry were the shores of the Firth of Forth, where the juxtaposition of the coal and the sea supplied

the necessary conditions for its manufacture. When it was proposed to restrict the export of Scottish Salt it was pointed out that the coal and salt industries were inseparable—10,000 persons were engaged in the working of both. Should the production of salt be largely diminished the result must be a proportionate decrease in the output of coal.

3. "Observations on Flinty Crush Rocks." By Professor T. J. Jehu, M.D., F.G.S.

Flinty Crush Rocks have been described in many regions, and their mode of origin has given rise to much discussion. The typical flinty crush material is so dark and structureless in hand specimens that it might be taken for an igneous rock; and it behaves towards the surrounding rocks in an intrusive fashion. Bands and veins of the flinty crush material traverse the country rocks in all directions, sometimes resulting in the production of a pseudo-conglomerate. In the southern islands of the Outer Hebrides the flinty crush phenomena are found in association with crush zones and shearlines, running in definite directions. The fragments of gneiss and pegmatite in the pseudo-conglomerates are sometimes so well rounded as to suggest corrosion, and are themselves shot through by the fine dark material of the matrix in which they lie. Under the microscope, evidence is afforded of all stages in the breaking down of the gneisses, and the partial fusion of the mashed and ground down materials; followed at places by subsequent incipient crystallization. Beautiful examples of fluxion structure are seen in the streaking and banding of the fused or partially fused matrix, with eddies and invasions of portions of the viscous paste into each other. Examples also occur of the development of abundant spherulites, and more rarely of felspar microlites arranged in radial groups. The behaviour of the material in the field, together with its macroscopic and microscopic characters, points to the conclusion that this peculiar rock is the product of mechanical stresses, which at places have raised the temperature to an extent sufficient to bring about partial fusion of the crushed gneisses. There is no evidence in the Outer Hebrides that these phenomena are the result of earthquakes caused by deep-seated explosions, accompanied by the outrush of incandescent gases.

OBITUARY.

Henry Keeping.

BORN FEBRUARY, 1827. DIED JANUARY, 1924.

The death of Henry Keeping on 31st January, within a few weeks of his ninety-seventh birthday, removes one of the few remaining links with the great geologists of the earlier half of the last century. Though well known to many of the present older generation, he had lived in retirement for some years.

Born at Milton, in Hampshire, his attention was directed at an

early age to the fossils of the Tertiary strata of the Hampshire Basin, of which he became a keen collector. He was employed for this purpose by the Marchioness of Hastings and by the Rev. Osmond Fisher, while in 1864 Professor Sedgwick appointed him Curator of the Woodwardian Museum, and this post he retained till his retirement in 1911. During these years he made frequent field expeditions and collected largely, not only from Tertiary strata, but also from other deposits, including the Olenellus beds of Shropshire. The magnificent collection of Tertiary fossils in the Sedgwick Museum owes much to his labours, and as a collector he was perhaps unrivalled.

But he was more than this. His eye for new species among the Tertiary fossils was unerring, and he contributed several papers to various scientific journals, chiefly on the Hampshire Basin, but also on Mesozoic deposits around Cambridge.

He was a sociable man and interested in many matters outside his own special domain. A few years ago he published a short autobiographical sketch entitled *Reminiscences of My Life*. This not only records the chief events of his career, but gives an insight into his character.

His son, Walter Keeping, who predeceased him by many years, was also a well-known geologist and palæontologist, and for some time was Professor of Geology at Aberystwyth.

Professor F. Omori.

BORN 1868. DIED 8TH NOVEMBER, 1923.

For the last thirty years we have grown accustomed to the constant stream of papers from the full-stored mind of Professor F. Omori. Numerous as the papers were, there was not one of them that did not add to our knowledge of earthquakes and volcanic phenomena, and some of them have taken an honourable place among the contributions that seem likely to last for generations yet to come. Among these may be mentioned his memoirs on the after-shocks of earthquakes, a subject which he made his own, the distribution of Japanese earthquakes in time and space, and the remarkable eruptions of the Usu-san, Asama-yama, and Sakura-jima. In a country like Japan, and to one in his official position—he was Professor of Seismology and the leading member of the Imperial Earthquake Investigation Committee—it was only natural that he should give close attention to the vibrations of buildings and various engineering structures during earthquakes. One of his latest papers dealt with the effect of semi-destructive earthquakes on the new steel-brick buildings in Tokyo, and his conclusion that they might be trusted to withstand the fiercest shock was amply confirmed on 1st September last. On that day he was absent from Tokyo, but he returned shortly afterwards, and died on 8th November at the age of 55, after spending more

than half his life in the single-hearted pursuit of science and of kindly service to his fellow-men.

C. D.

CORRESPONDENCE.

THE VOLCANIC GEOLOGY OF EAST FIFE.

SIR,—Mr. Balsillie is to be congratulated on his resolute tackling of the Carboniferous igneous rocks of Fifeshire. It may be permissible, however, at the same time, to express regret that in his latest paper [1] he has countenanced the idea of the Lower Carboniferous age of the East Fife vents on the basis of evidence obtained from one of the least typical of them.

Everyone must agree that the evidence Mr. Balsillie has marshalled is overwhelmingly in favour of the Lower Carboniferous age of the Largo Law vent. It is one of the largest of the Fife vents, very different in size from the small "greenhill" type of vent which appears to be characteristic of late-Carboniferous and Permian vulcanicity. It appears to resemble the great vent of the Heads of Ayr,[2] which is also demonstrably of Lower Carboniferous age, but which, unlike Largo Law, has not proceeded to eruption of lava. It is full of fragments of the subjacent Old Red Sandstone andesites, and not a single fragment of Lower Carboniferous lava has been found in spite of repeated search. Hence the small basic alkaline intrusions by which it is pierced are probably of much later age. There can hardly be any doubt but that the Heads of Ayr volcanic channel has been utilized by the recrudescent late-Carboniferous igneous activity. I would suggest that the similar intrusions in Largo Law are also possibly of later date than the main filling of the vent; and in this connexion it would be interesting to have a petrographical comparison of the unquestionably intercalated ash, agglomerate, and lava, with the material filling the volcanic orifice or orifices. Later agglomerate fillings may perhaps be distinguishable from earlier (e.g. the large blocks of earlier ash in the western vent of the Largo shore, Mr. Balsillie's paper, p. 541).

The argument for the late-Carboniferous or Permian age of many of the Fifeshire vents does not rest entirely on petrographical evidence; and the fact that analcite- and nepheline-bearing rocks occur in earlier stages of the Carboniferous igneous period has little bearing on the problem. Such rocks in similar age relations are found also in the Bathgate Hills and in the west, but clearly do not militate against the Permian age of the western vents of the Fife type. Many of the analcite-basalts and monchiquites, as well as teschenites, of East Lothian are stated in the East Lothian

[1] GEOL. MAG., Vol. LX, 1923, pp. 530–42.
[2] *Trans. Geol. Soc. Glasgow*, vol. xvi, 1917–18, pt. iii, pp. 340–3.

Memoir to be intrusive into rocks of the upper part of the Carboniferous Limestone Series. It is therefore difficult to believe that these rocks (which are identical with the vent intrusions of Fifeshire and Ayrshire) can be connected with Lower Carboniferous vulcanicity.

The argument from analogy has been used in comparing the ages of the Fifeshire and Ayrshire vents. The numbers, sizes, and contents almost exactly correspond in the two cases; but whereas the Ayrshire vents cut late-Carboniferous rocks, only one of the Fife examples cuts the Millstone Grit, and one doubtful case the Coal Measures. Admittedly the argument from analogy must be used with extreme caution, but it is fairly strong in this case. If the Ayrshire region had been eroded, say, 1,000 feet deeper, most of the Upper Carboniferous would have been cleared away, the geological relations of the vents would have been very similar to those in Fife, and the same arguments as those used by Mr. Balsillie might have been advanced to prove their Lower Carboniferous age.

G. W. Tyrrell.

Geological Department,
University of Glasgow.
17th December, 1923.

DIATOMACEOUS EARTH IN EGYPT.

Sir,—When examining oil-well samples from a recently drilled test-bore undertaken by the Egyptian Government at Abu Shaar on the western shores of the Red Sea, I was struck by the presence of small round objects just discernible by the aid of a pocket lens, in beds of siliceous laminated shales.

Having prepared a slide of the material for examination under the microscope, I submitted it to Dr. W. F. Hume, Director of the Geological Survey of Egypt, who recognized the presence of the diatom *Coscinodiscus*, this being the first time fossil diatoms have been noted in Egypt.

These shales, or diatomaceous earths, occur interbedded in the gypsum-salt series which we regard as belonging to the upper part of the Miocene succession—a series which is strongly developed in the oilfields region of this country, and which has been looked upon for some time past as representing lagoon conditions.

Colonel H. G. Lyons was informed of the discovery, and at his suggestion a sample of this material was sent to Dr. Rendle, of the British Museum, Natural History Department, and was subsequently submitted to Sir Nicolas Yermoloff, who identified forty-five different species belonging to the following ten genera:—

Coscinodiscus.
Actinocyclus.
Actinoptychus.
Chatoceros.
Rhizosolenia.
Biddulphia.
Eupodiscus.
Rhabdonema.
Surirella.
Navicula.